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**INFORMATION REDUCTION – ALL, NOTHING, OR SOMEWHERE
IN-BETWEEN?**

An Exploration of the Information Reduction Strategy in Practice Learning

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BA (Hons); BSc (Hons); PG Dip (PRM); MSc

Thesis submitted for the degree of Doctor of Philosophy in the discipline of Psychology

The Open University

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ABSTRACT

Practice leads to performance gains in speed and accuracy. Investigations have indicated these may occur due to use of cognitive strategies. One such strategy, previously investigated with an Alphabet Verification task, is called Information Reduction (Haider and Frensch, 1996). It involves attending to and processing only information relevant to the task in hand. Information Reduction has been proposed to be consciously and abruptly adopted and applied consistently. However, it has been observed that not everyone makes use of this strategy. This could be due to the nature of the task, the conditions under which learning takes place or characteristics of the participants.

Using new tasks developed for this study, plus post-testing questionnaires, further investigations were carried out. These confirmed Information Reduction is not a task-specific phenomenon, but demonstrated that the instructions and feedback given have considerable effects on whether irrelevant information in the stimuli is ignored. When instructed that a shortcut could improve performance, only one-third of participants could verbalise Information Reduction use, although another third adopted it, apparently without awareness. Using Information Reduction without awareness is at odds with Haider and Frensch's hypothesis about the mechanism. However, experiments testing transfer to other stimuli where the same regularity occurs or with similar stimuli obeying a slightly different rule suggested that conscious knowledge may be required for transfer to be successful.

One notable result from all experiments is that Information Reduction is often not used consistently. Whilst this may seem to be in line with the idea that it is consciously applied, it is not with other aspects of the proposed mechanism. Overall

it does seem to be less robust than has been suggested and there seems to be some way to go before an adequate theory to explain Information Reduction can be developed.

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DEDICATION

For my wonderful husband Dave, and in loving and grateful memory of my father

Bob Milton, who was so proud of me.

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Chapter 1 INTRODUCTION

There is an old adage which says that 'practice makes perfect' and our everyday experience is that tasks do become more easily, accurately and quickly performed after repeated practice. This performance improvement has been of interest to psychologists for decades, from Bryan and Harter's (1899) investigation of rate of learning in telegraphy through to the present day. Psychologists are interested in elucidating the knowledge, processes and strategies which facilitate the improvements seen, and ultimately in devising ways in which learning might be optimised.

In learning, knowledge is acquired which leads to changes in behaviour and this can develop into a skill, that is, an accomplished, complex and organised pattern of behaviour. Learning is something which usually takes time, although the amount of time needed can vary enormously from one task to another. This can depend on factors such as the complexity of the task, as well as processing differences between learners. On the whole learning occurs explicitly, particularly where a skill is concerned, although alongside the known learning there can be incidental or unintended learning. Some learning may occur implicitly, that is, it is considered to occur without conscious effort or possibly even awareness of what has been learned. One example of implicit learning would be learning to speak grammatical sentences alongside learning to speak words.

Learning of skills takes both time and repeated practice. All individuals develop, and become competent in, a variety of skills throughout their lifetime, including 'everyday' cognitive skills such as the ability to use language, and motor skills, such as walking. In today's societies most learn to read, write and perhaps drive a vehicle, and become reasonably proficient in these. A few may be considered

expert, that is, consistently, reproducibly and reliably superior performers, for example professional writers and motor racing drivers. Skill is needed in many occupations. Historically this was in trades such as carpentry or masonry, with apprentices learning 'on-the-job' from those who were already skilled. In the last century skills such as typing were taught initially in classrooms before the workplace was entered. Increasingly, skilled work involves monitoring and acting upon complex computer displays, for example in air-traffic control or electricity-generating stations. A common element to all these is the fact that the skill cannot develop from watching others, or from being given instructions, but requires the learner to actually perform the task regularly over a period of time, in order to become faster and less error-prone.

The development of skill leads to changes in perception, cognition and motor responses (Ericsson, Krampe, & Tesch-Römer, 1993). The time taken to improve speed and accuracy in any specific task varies between individuals and not everyone achieves the highest levels of skill. It has become clear that general innate mental abilities such as IQ or memory do not generally determine the level of skill attained (see Ericsson & Lehmann, 1996, for a review), although these abilities may be important during learning. Studies have repeatedly found that, regardless of domain, skill acquisition follows a similar pathway (Newell & Rosenbloom, 1981), which indicates that similar cognitive processes are operating. Central to this are the development of automatic processes, moving from the effortful, slow, serial and intentional processing of controlled tasks to effortless, fast, parallel and unintentional processing (Moors & De Houwer, 2006; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Any particular skill may involve several automatic processes, which need to be co-ordinated (Strayer & Kramer, 1994).

Automation of cognitive processes may occur as a result of repeated incoming data or repetition of the processes involved (Anderson, 1987; Logan, 1988; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) and occurs regardless of the task or domain. Since this automaticity develops from the incoming stimuli, it can be described as 'bottom-up' or data-driven, and is considered to be an inevitable result of practice. The two main theories for the development of automaticity in practice learning are the Production rules/algorithm-strengthening theory of Anderson (1987), which involves procedural memory, and the Instance theory of Logan (1988), which involves episodic memory. These theories and others around automaticity will be considered in the literature review (chapter 2). Logan theorises that many automatic processes may make use of single-step direct retrieval of the relevant response (Logan & Klapp, 1991) and depend on having encountered that particular stimulus before. Anderson's theory suggests that it is the processing a stimulus receives which is automatised, although he has suggested that both proceduralisation and instance recall operate to varying degrees depending on the type of stimuli being encountered (Anderson, Fincham, & Douglass, 1997). Intuitively, the use of one over the other in different conditions seems plausible – motor skills such as riding a bike use procedural memory, whereas cognitive skills like reading use 'instances' in declarative. As will be seen, the theories proposed suggest that the same information is processed but in a more efficient way, thus leading to improvements in performance.

Additionally processing can be strategically affected, that is, driven by stored knowledge (known as 'top-down'). Developing strategies, either implicitly or explicitly, can enhance skilled performance. The development of automaticity may be influenced by the interaction of data-driven and strategic processes (Strayer & Kramer, 1994). A strategy could be defined as a set of operations which allow a

problem to be solved or a goal achieved more quickly and accurately than can be achieved with automatic processing alone. Strategies can be general and transferable from one task to another if they have the same stimulus-response conditions, or they can be stimulus- or task-specific and not transferable (Strayer & Kramer, 1994). One such strategy would be to attend and process only information that is relevant to the task in hand. Such a strategy will make more efficient use of limited cognitive resources and so is particularly useful in situations where a great deal of information is available simultaneously. This has been reported, both anecdotally and empirically, in a number of areas. Examples of experimental and applied areas include visual search (Shiffrin & Schneider, 1977), air traffic control (Lee & Anderson, 2001; Niessen, Eyferth, & Bierwagen, 1999) and radiology (Kundel, Nodine, Conant, & Weinstein, 2007). It may also be used in more ‘everyday’ situations such as processing of labels on food packaging (Gaschler, Mata, Störmer, Kühnel, & Bilalić, 2010) and shopping online (Gaschler, Marewski, & Frensch, 2015).

1.1 INFORMATION REDUCTION

This strategy of learning, over the course of practice, to ignore irrelevant or redundant information at a perceptual level has been termed Information Reduction. It has been investigated experimentally (Gaschler & Frensch, 2007; Gaschler & Frensch, 2009; Gaschler et al., 2015; Green & Wright, 2003; Haider & Frensch, 1996; Haider & Frensch, 1999a; Haider & Frensch, 1999b; Haider, Frensch, & Joram, 2005), mainly using a task where participants were required to check whether a sequence of letters was alphabetically correct or not. This is known as the Alphabet Verification task, and will be described in more detail in Chapter 3. Each stimulus consisted of an ordered string of letters where either four or five letters after the initial letter were replaced by the bracketed digit (4):

D [4] I 4 letters replaced = correct string, 'triplet' only

H [4] N O P Q 5 letters replaced = incorrect string

The task was a two-alternative forced choice response determining whether it was four letters which had been omitted, giving a 'correct' response, or five letters, giving an 'incorrect' response. Participants were instructed that errors could occur anywhere in the entire string, so initially verification times varied systematically with the number of letters in the string. However, if participants learned over the course of practice that they needed to check only the initial letter-digit-letter triplet and could ignore any trailing letters, the verification time for longer strings would decline to equivalence with the shorter strings – a reduction in the 'string-length effect'. After training it was possible to examine if the trailing letters were being ignored by administering a test block where in some strings the triplet was correct but the trailing letters, previously irrelevant, started to contain alphabetic inaccuracies. Many participants responded that these 'irregular' strings were correct, indicating they were only processing the (correct) triplet and ignoring the (incorrect) trailing letters. Consequently there was a high rate of errors to these strings. Other participants noticed the change in position of the errors and reverted to checking the whole string, causing a return of the string-length effect.

Results from the various experiments have indicated that:

- the strategy can be implicitly learned, it is not necessary to inform people of the redundancy (Haider & Frensch, 1996)
- once implemented the strategy is used for all stimuli of that type and that it can be transferred to structurally very similar stimuli, suggesting that it is not stimulus-specific (Haider & Frensch, 1996; Haider et al., 2005)

- speed instructions may cause it to be adopted more quickly whereas accuracy instructions can slow rate of acquisition (Haider & Frensch, 1999b)
- stimuli need to consistently incorporate irrelevant information during training for Information Reduction to develop (Gaschler & Frensch, 2009; Haider et al., 2005), although the number of times each individual stimulus is encountered overall does not affect strategy adoption
- it is reportable (Haider & Frensch, 1999a; Haider et al., 2005)
- it is not an artefact of left-to-right reading (Green & Wright, 2003; Haider & Frensch, 1999a).

Although some of these results can be accounted for by Instance theory, the Production rules theory or a combination of both, others rule out these theories of automaticity as a sole explanation of the performance improvement seen. Instance theory cannot account for the item-generalty found in Information Reduction (Doane, Sohn, & Schreiber, 1999; Gaschler & Frensch, 2007; Haider et al., 2005). Anderson's theory is item-general and so can accommodate transfer to novel stimuli but cannot account for apparently conscious aspects of the strategy, such as the effect of changing the task instruction (Haider & Frensch, 1999b). A combination of the two might conceivably account for both item-generalty and the effects of change instructions, particularly when considering precisely what an instance may contain and whether the instances activated have to be identical to the stimulus, or just contain similarities. However, neither theory can account for changes at the perceptual level, which an eye-tracking experiment has demonstrated (Haider & Frensch, 1999a) and has also been inferred from other experimental results (e.g. Green & Wright, 2003).

Consequently, Haider and Frensch (1999b) have proposed a two-stage Information Reduction hypothesis. The first stage of Information Reduction (relevance detection) is considered to be implicit and data-driven, whereas the second (information selection) is strategically and consciously applied. Haider and Frensch have suggested that Information Reduction:

- is a general and non-domain-specific learning process that is not an inevitable consequence of practice
- may operate in addition to other learning mechanisms
- is used consistently on all stimuli of the same type from the point of adoption onwards, even if the actual instance has not previously been encountered
- is abruptly adopted, rather than gradually, although the switch occurs at different times for each individual, meaning that when the learning curves are aggregated, the normal power law curve is seen (Haider & Frensch, 2002).

The results from the various experiments, deductions from these and potential theories around how a person becomes aware of the strategy will be considered in more detail in the literature review (chapter 2).

1.2 DEVELOPMENT OF RESEARCH QUESTIONS

Results from some experiments indicate that only around half of participants adopt the Information Reduction strategy in the Alphabet Verification task (Haider & Frensch, 2002; Haider et al., 2005). Those who adopt Information Reduction have been referred to as ‘reducers’, with those not using it called ‘non-reducers’.

Additionally, results of post-testing questions suggest that not all reducers are

consciously aware that parts of the stimulus are irrelevant to the task (Haider & Frensch, 2005). There are some hints in the literature of factors which could be involved in some being reducers and others non-reducers, including individual differences (Sohn, Doane, & Garrison, 2006); use of other strategies (Doane et al., 1999); and training conditions (Gaschler & Frensch, 2009; Haider & Frensch, 1999b; Haider & Frensch, 2002; Haider & Frensch, 2005). If Information Reduction is an abruptly and consistently adopted strategy, as has been suggested (Gaschler & Frensch, 2009; Haider & Frensch, 2002), then it should be possible to determine who is using it and who is not. At the start of the study for this thesis it was noted that the Information Reduction hypothesis had been derived from results using only the Alphabet Verification task. This could mean that the hypothesis was based on aspects of this task unique and artefactual to it and that in fact the proposed Information Reduction process is not a general learning process.

Having considered the published research, it seemed that further investigation of Information Reduction would add to the body of knowledge around this phenomenon. It would appear to be a useful and adaptive mechanism for focussing attention on relevant aspects of the world, but potentially could also lead to problems if the irrelevant information becomes relevant at any point. Thus it might be 'safer' and more adaptive to be a non-reducer, at least in certain situations. A number of areas for possible research were developed, which together could contribute to exploring what factors might be involved in determining whether or not individuals adopt the Information Reduction strategy, and the level of conscious awareness of the strategy amongst reducers.

The research questions to be explored were:

- is Information Reduction a mechanism of human learning or merely an artefact of the Alphabet Verification task?

- is it possible to identify those using the Information Reduction strategy from the experimental data (error rates and response times) and from self-reports?
- do manipulations of task and/or training conditions affect the number of people adopting an Information Reduction strategy?
- what, if anything, can be learned about the conscious nature of the strategy from manipulations of training conditions and testing participants' conscious knowledge post-testing?
- are there any processing or personality differences which point to whether someone will be a reducer or a non-reducer?

As well as potentially being able to inform occupational training, these questions have implications for the Information Reduction hypothesis. If it proves to be an artefact of the Alphabet Verification task then alternative reasons for the apparent ignoring of irrelevant parts of stimuli in other fields would need to be sought. If the adoption rates vary with different tasks or training conditions, then this could be evidence for Information Reduction being a conscious process, which can be used when the individual feels it gives an advantage – although the point at which this is true may differ between individuals. However, if manipulations of task and training reveal that Information Reduction is only used by a sub-set of people, then this would indicate that it is not a general learning process and exploration of why not everyone appears to have this strategy at their disposal would be indicated.

1.3 STRUCTURE OF THE THESIS

The next chapter is a literature review, looking at some of the background to practice and implicit learning and the theoretical propositions derived from studies in it, before moving on to examine the evidence for strategy development in a variety of tasks. Experiments which have examined Information Reduction will be

considered in some depth and finally the issue of processing and personality differences between groups of people will be explored.

In chapter 3 the methodology of the experiments will be considered, before moving on to the various experiments performed themselves, in chapters 4-9. All experiments were followed up by a questionnaire designed to elicit whether participants were aware of the regularity and if they made a conscious decision to use it or not. The first experiment tested three tasks which could potentially lead to Information Reduction: a multiple-triplet version of the Alphabet Verification task, a shapes task and a target search task (the last originally developed by Edmunds, 2005). Having established that all these tasks could be used to investigate the strategy, the two unique to this study were carried forward. Experiment 1 then became a control for the other experiments to determine the effect of the various manipulations. In Experiments 2 and 3 training conditions were varied by changing the feedback given and by emphasising speed over accuracy. Conscious awareness was further tested in Experiment 4 by informing participants that some people find a shortcut to enable faster responses and asking them to indicate if they had done so, at which point one further training block was given before the test block. Experiment 5 looked at the issue of transfer from one set of stimuli to another, firstly a 'near transfer' situation where the rule for which information was relevant remained the same, although the stimuli altered, and secondly a 'far transfer' where the rule changed.

Chapter 8 explores some processing and personality differences, known as individual differences, which were examined alongside Experiments 4 and 5. These encompass personality factors such as the 'Big 5' of agreeableness, conscientiousness, extraversion, neuroticism and openness to experience, as well as related factors like impulsivity and distractibility. More cognitively related factors

explored were trust in memory and a measure of 'cognitive miserliness'. Finally, chapter 10 will summarise the findings overall, discussing them in relation to theory and considering ways in which the research could be extended, as the results suggest that Information Reduction is less robust than had previously been noted. Neither the hypotheses proposed by Haider and Frensch about the mechanism of Information Reduction, nor the existing theories of automaticity, are sufficient to explain the strategy, and a theory of practice learning which incorporates both data-driven automaticity and top-down controlled processes may provide a better overall explanation.

Chapter 2 LITERATURE REVIEW

In this review some of the background to practice and implicit learning and the theoretical propositions derived from studies in it will be considered, before moving on to examine the evidence for strategy development in a variety of tasks. This leads into outlining the experiments using the Alphabet Verification task. Finally, the issue of processing and personality differences between groups of people, known as individual differences, will be explored.

2.1 LEARNING LEADS TO SKILL DEVELOPMENT

Both explicit and implicit learning have been implicated in skill acquisition. Explicit learning often takes place under the guidance of a teacher, for example within a school or in an apprenticeship situation, and requires attention to all aspects of the task as well as practice. Implicit learning by definition occurs without conscious awareness of what is being learned, although some attention is paid to the stimulus. This section considers further the role of practice in developing not just skill but also expertise, the way that measures of improvement all point to common learning mechanisms and also some of the evidence for implicit learning.

2.1.1 Investigating practice and expertise

It is generally accepted that to become skilled in some field one has to invest both time and effort, and that the skill needs to be repeatedly and regularly practised for both acquisition and maintenance. Psychologists have been investigating the speed and accuracy changes in performance that develop from practice for well over a century. Learning seems to progress through the same stages, whether the skill being developed is perceptual-motor or 'intellectual' (Rosenbaum, Carlson, & Gilmore, 2001). These stages are considered to be: declarative, when the basics of the task are being learned; associative, when the procedures of the task become more

fluent; and finally autonomous, when the procedures become automatic and less susceptible to disruption from external events (Anderson, 1982). It has been found that regardless of task the rate of skill acquisition shows the same pattern. Section 2.1.2 looks more closely at this 'power law' as it has become known.

Some people can become highly skilled at a task and considered to be experts in that particular domain. It is often stated that expertise takes 10 years of methodical and sustained practice to develop (Simon & Chase, 1973) and this has been noted in many domains, such as medicine (Norman, Eva, Brooks, & Hamstra, 2006), mathematics (Butterworth, 2006), sports (Hodges, Starkes, & MacMahon, 2006), performing arts (Ericsson et al., 1993) and strategy games (Feltovich, Prietula and Ericsson, 2006), although this is not necessarily the case for all skills or all practitioners. Ericsson and colleagues have carried out a number of studies in the area of expertise. Their results, from testing expert and amateur pianists, indicate that superior performance is a result of domain-specific mechanisms rather than general cognitive-motor abilities. They contend that variations seen in individuals' performance levels in a wide range of domains are directly related to the accumulated amount of deliberate practice undertaken (Ericsson et al., 1993). Deliberate practice involves specifically aiming to improve, perhaps incorporating feedback from an instructor. Nonetheless, not all individuals achieve the highest levels of performance. It may be that personality and other factors such as 'talent', 'interest' or 'motivation' act to predispose individuals to undertake and maintain deliberate practice and enable them to become highly skilled in their field.

Ericsson et al. consider that practice changes basic perceptual, cognitive and motor abilities and that this is the main factor driving the development of expertise. Perceptual-motor changes have been detected in reading and also sight-reading in musicians (Lehmann and Gruber, 2006). A cognitive aspect of skill acquisition is the

storing of domain-specific knowledge which enables experts “*to encode meaningful relations between the elements of the stimuli*” (Ericsson et al., 1993, p396). Studies have shown that skilled performers and experts are able to store and access relevant information in long-term memory more rapidly than those with less skill. This has led Ericsson to propose a theory of long-term working memory. Some theories relating to cognitive changes will be considered in section 2.2 and long-term working memory will be elaborated in section 2.2.6. In motor skills, future events are anticipated and planned for in advance – this can be seen in domains such as touch typing (Salthouse, 1986) and tennis (Farrow, Chivers, Hardingham and Sachse, 1998).

The cognitive, physiological and perceptual-motor adaptations that occur as a result of practice may be specific to the particular skill or domain, meaning that skill in one domain will not transfer to another, even an apparently similar one. This has been noted within the domains of strategy games (Feltovich et al., 2006), surgery (Norman et al., 2006), sport (Hodges et al., 2006) and music (Lehmann and Gruber, 2006). Early psychology experiments also suggested that transfer does not occur (Woodworth & Thorndike, 1901). However, many subsequent experiments have shown that positive transfer can occur, with the skill helping to maintain or improve performance in a second task (Chein & Morrison, 2010; Chen & Klahr, 1999; Karbach & Kray, 2009; McAllister, 1953; Schwager, Rüniger, Gaschler, & Frensch, 2012; Singley & Anderson, 1985). The stimuli, the task, the responses and the generality of any strategy employed, as well as the nature of the practice involved and the shared nature of the procedural memory productions required, determine whether, or how successfully, transfer occurs (Adams, 1987; Barnett & Ceci, 2002; Speelman & Kirsner, 1997; Strayer & Kramer, 1994; Taatgen, 2013).

It is clear that practice plays a role in all types of skill acquisition and particularly in the development of expertise. Practice is required to create the knowledge base on which skill resides, as well as to drive physiological and perceptual-motor changes that enable better performance.

2.1.2 The Power Law

As noted in section 2.1.1 the increase in speed and accuracy seen as skill develops over time has been noted to follow a similar curve regardless of the task. This has been deduced by setting regular timed tests as someone learns a skill e.g. Bryan and Harter's study of telegraphy (1899) or Chapman's study of typewriting (1919), or by creating a novel task which is practised repeatedly in a relatively short space of time, again with regular testing during the acquisition of the skill, e.g. Snoddy's mirror drawing task (1926) or Koler's reading of inverted text (1975).

In some instances an individual's curve may show a plateau and although some have called into question the existence of this plateau (Keller, 1958), other theorists believe that it indicates the development of, or a change in, a strategy, enabling faster and more accurate performance. The point at which such discontinuities occur varies between individuals so that when aggregated data is plotted a smooth curve is obtained. A logarithmic scale plot results in a straight line. Figures 2.1 and 2.2 illustrate a typical curve of how aggregated performance changes with time in a practice learning study, and how logarithmic transformation results in a straight line.

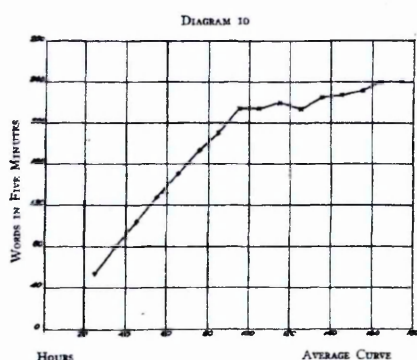


Figure 2.1: Increase in number of words typed in 5 minutes over hours of practice. Taken from Chapman (1919)

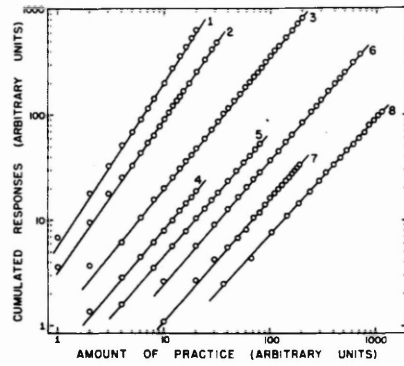


Figure 2.2: Cumulative learning curves in log-log co-ordinates from various studies. Replotted by Stevens and Savin (1962)

This was formally noted by Newell and Rosenbloom (1981) and they refer to it as the ‘power law of practice’. It is now accepted that any theory which purports to explain practice learning has to be able to accommodate the power law. Some theories which do this are outlined in section 2.2. Newell and Rosenbloom concluded from examination of a number of studies published over the years that the law holds for all kinds of practice learning: perceptual only, mainly motor, perceptual-motor and tasks which are mainly cognitive, involving memory or problem solving. They also say that it holds for various forms of performance criteria – speed and accuracy being the commonest measures - and that it can be demonstrated with either individual or group data. This all points towards there being common mechanisms underlying all practice learning, and theories about these processes are described in section 2.2.

2.1.3 Implicit learning

It has been suggested that alongside the explicit learning which results from attention being given to the various stimuli and responses, implicit learning may be involved in the acquisition of skill. Implicit learning is learning that occurs without the explicit intention to learn and often without awareness of what has been learned (Frensch & R nger, 2003) or the ability to express the learning (Dienes & Berry, 1997). Implicit learning was first suggested as a mechanism for improvements in an artificial grammar task. This used a string of letters which follow an underlying ‘rule’,

although the task was presented simply as a memory task (e.g. Reber, 1967).

Subsequently implicit learning has been implicated in other tasks such as serial reaction time (SRT) tasks where a longer-than-normal-digit-span repeating sequence is used, to which participants have to respond with key presses (e.g Nissen & Bullemer, 1987). Less error-prone learning of the 'sentences' than a control group, better-than-chance ability to distinguish grammatical strings from non-grammatical ones or slower response times (RT) when the sequence is disrupted are taken as indicators that implicit learning of the underlying structure has occurred. In grammar learning tasks some practice is involved but this may not be extensive with perhaps just 30 strings of various lengths presented (Gebauer & Mackintosh, 2007) before moving on to the test phase. SRT tasks, on the other hand, may require several 'training' blocks with a hundred or more trials in each. This suggests that implicit learning may have a role to play in practice learning.

Implicit learning is generally considered to be an elementary, obligatory and unintentional ability to extract structure from the environment as a result of processing events or stimuli within it (Jiménez, 2003), where either stimulus dimensions relevant to processing or responses or both are selectively attended. Implicit learning is thought to be both independent of, and dissociated from, awareness (Shanks, 2003), since it results in behaviour that is not consciously attributed to learning (Jiménez, 2003). Jimenez considers implicit learning to be something which can affect the whole of cognition, including our representations of the world, as well as behaviour and possibly consciousness, and may not be a separate system to explicit learning. Implicit learning has been suggested as a mechanism by which strategies may develop, where repeated patterns or relationships between the stimuli may lend themselves to more efficient processing (Haider & Frensch, 1996).

However, implicit learning is hard to define and operationalise theoretically (Frensch & R nger, 2003) and the evidence is equivocal as to whether it occurs independently of attention or that any implicitly learned knowledge is not accompanied by some level of awareness (Shanks, 2003). Questions have also been asked about what exactly is implicitly learned (Shanks, 2005). It may be that the participant has merely explicitly learned some pairs or triplets of adjacent letters or parts of the sequence and an explanation of this nature could then be accommodated in, for example, Logan's instance theory (see section 2.2.3), without the need to invoke different learning mechanisms. Memorising fragments could also account for why the participants do not seem to be aware of the gross regularities but can only verbally report small patterns. Not all presented sequences may be learned, or it may not be the regularities in the stimulus which are learned but the regularity in the responses (Riedel & Burton, 2006). Using spoken words which followed a regular recurring sequence on two dimensions (colour words and voice used, with different sequences for each), they established that only the sequence which had to be responded to was learned. Riedel and Burton suggest that this indicates that implicit learning is tied to peripheral processes, not central cognitive processes. Nonetheless an extensive literature exists which suggests that implicit learning occurs and attempts to determine the processes behind it.

Once implicit learning has occurred, then there may be some explicit awareness of what has been learned. For example some participants may be able to report fragments of the grammar, or parts of the sequence (Curran & Keele, 1993; Lambert & Roser, 2001; Schwager et al., 2012; Zirngibl & Koch, 2002). The question then arises of how or when the implicit knowledge becomes available to conscious, declarative processes. A number of theoretical positions have been suggested for this, which will be considered next.

This position suggests reportable knowledge exists because the explicit system, as well as the implicit, has been involved in the learning, although the learning occurs separately. Some theorists additionally separate attention from awareness and suggest there are three types of sequence learning (Curran & Keele, 1993). These are: non-attentional, which operates by simple associations, attentional with awareness and attentional without awareness. The latter two have a mechanism for encoding the position of an event in a sequence. It is suggested that the attentional and nonattentional systems do not share information, although they may share common components at the implementational level.

Explicit and implicit learning may occur in parallel when there are physical responses given to stimuli (Curran & Keele, 1993; Willingham & Goedert-Eschmann, 1999). It is suggested that the explicit knowledge guides movement and that a conscious explicit process supports behaviour until the simultaneously learned implicit representation is sufficiently well developed, at which point the explicit process is no longer used (Willingham & Goedert-Eschmann, 1999). Cleeremans (1993) has suggested that explicit knowledge serves as input for the implicit learning mechanism. He concluded, from a comparison between groups given a hint or not to find a regularity, that reportable knowledge may be influenced by individual differences in attention allocation and short-term memory capacity, accounting for the fact that the amount of reportable knowledge varies between participants.

This position derives from work with connectionist networks and suggests that it is the strength of the representation which determines whether it is explicitly available or not (Cleeremans and Jiménez, 2002). Implicit and explicit knowledge lie on a continuum and are aspects of a single set of underlying neural mechanisms. In order for knowledge to be available to conscious awareness and be reported verbally the representations need to be strong, stable and distinct (Frensch et al., 2003). As the cognitive system processes the stimuli over time, the weights between the units of the network are continually adjusted and come to capture the correlational structure of the task. As the task is practised, the representations become stronger and available to verbal report, although this may also need attention and other processes integrating the activity of different brain regions. With more practice the representations become very strong and automatic, that is, it is difficult to alter their influence on processing, but there is metaknowledge of their existence and effect (Cleeremans and Jiménez, 2002). Variability in reportable knowledge occurs because different people have different thresholds for when the representation is strong enough to be available to consciousness.

An alternative view which assumes implicit knowledge is the starting point is that reportable knowledge depends on which aspects of knowledge (the propositional attitude) get represented (Dienes & Perner, 1999) – that is, whether there is awareness that knowledge is possessed or awareness of what that knowledge is (Dienes & Berry, 1997).

This position, known as the Unexpected-Event hypothesis (Frensch et al., 2003), builds on the first two theories in order to consider the mechanisms involved in the acquisition of reportable knowledge and why some participants can report regularities and others cannot. It suggests that an unexpected event, such as a feeling of familiarity or a rapid motor response prior to the processing of a stimulus (or even the appearance of a stimulus in the SRT), triggers an intentional search for an explanation of that event by an explicit reasoning system. In other words, explicit hypothesis testing drives attentional strategies to examine the structure of the task. Once a causal factor has been identified, such as the fact the stimuli are appearing in a regular sequence (SRT) or that the trailing letters are redundant to the task (Alphabet Verification task), then this phenomenonal awareness enables verbal report of the regularity, as well as transforming the implicit knowledge into explicit. If a regularity is identified the participant is able to apply their knowledge in order to reduce RTs from then onwards. Their RT data will show a discontinuity at that point and will no longer fit a power function. Using data from six participants (Haider & Frensch, 2002) and also re-analysing earlier Alphabet Verification task data, as well as using the Number Reduction Task, Haider and Frensch were able to demonstrate that in general those who showed a discontinuity could report the regularity, whereas those who did not, could not. They strongly believe that it is knowledge of the regularity which precedes the discontinuity and that this is shown by increased RT variances in the block preceding the discontinuity, as the hypothesis testing occurs. They presented empirical evidence to support this position. Any variable which affects the implicit learning system should also affect the verbal report (if it has not

been learned, it cannot be reported), but variables affecting the reasoning system should not affect the implicit learning.

This section has outlined the central importance of practice in the improvements noted in speed and accuracy and considered that some learning may be implicit. It has also been established that whilst common processes underlie practice learning, the rate of learning, the application of strategies and the amount of implicit knowledge which is also explicit may vary amongst individuals. The next section will consider some theoretical explanations for the cognitive changes which enable enhanced performance.

2.2 THEORETICAL BACKGROUND

Studies in practice learning point to there being underlying cognitive changes occurring as a task is practised. The changes occur after many encounters with the same stimuli or from using the same procedures repeatedly and result in faster and more accurate processing.

“The process of skill acquisition involves some form of specialization that creates efficient knowledge specific for a particular task” (Taatgen, 2013, p440)

Many changes are data-driven and therefore ‘bottom-up’ and involuntary. A number of theoretical models have been proposed to account for these performance changes. Firstly automatic processes will be considered, before moving on to two theories which have been proposed to explain how automaticity occurs, followed by some theories about how the stored information is organised.

2.2.1 Automatic processes

When a task, such as reading or learning to drive, is first encountered it has to be tackled in a conscious and controlled way (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977), with every element attended and subjected to cognitive processing. For instance, each letter has to be sounded out before being combined to make the word or sequences of muscle movements have to be produced to change gear and so on. Controlled processing is considered to be effortful, slow, serial and intentional (Moors and De Houwer, 2006). As the task is practised, performance becomes faster and less error-prone and this has been explained by automation of cognitive processes. Automaticity has been invoked as an explanation for performance gains in practice learning from the earliest studies – Bryan and Harter note that *“Only when all the necessary habits, high and low, have become automatic, does one rise into the freedom and speed of the expert.”* (1899, p357). Automaticity can be defined as involuntarily processing a stimulus or stimuli without conscious control. In psychological terms it is assumed to be a way to free up resources from a limited capacity system, allowing two or more tasks to be carried out simultaneously. Automaticity is considered to be unconscious, effortless, fast and obligatory (Moors and De Houwer, 2006). Automaticity generally develops through learning and practice and amongst other things is thought to give rise to such phenomena as the Stroop effect (MacLeod & MacDonald, 2000; Stroop, 1935). Development of automaticity leads to changes in attention, awareness, control, speed and accuracy (Moors & De Houwer, 2006).

The seminal work of Schneider and Shiffrin (1977; Shiffrin & Schneider, 1977) formalised the thinking on automatic processes, which they contrast with controlled processing. Following a series of experiments with variants of the serial search paradigm, testing either accuracy or response times, they concluded that if the same

stimuli, requiring a consistent response, are encountered regularly then automaticity develops. The stimuli are attended to and processed without conscious control, enabling faster and more accurate processing – in other words the development of skilled performance. Automatic processes are considered difficult to “*suppress, modify or ignore*” (Shiffrin & Schneider, 1977, p127). Concurrent inputs will not be attended to and in fact, effort is needed to switch attention to them if necessary. On the other hand automatic selection means that the process is insensitive to distracters, however many there are of them.

Two learning mechanisms which have been proposed to explain how automaticity develops are the Production rules/algorithm-strengthening view of Anderson and the single-step direct memory retrieval model of Logan, which will be described next.

2.2.2 Production rule architectures

Anderson (1987) proposed that practice results in knowledge being transferred from declarative to procedural memory and that continuing practice strengthens the trace to the stored procedure so its use becomes automatic. Anderson’s theory is process-based not item-based and the process or algorithm must be consistent for automaticity to develop. Anderson’s theory is based on a symbolic computer model (ACT*, later developed to ACT-R) and is a modular domain-general learning theory which suggests that practice results in elaborate cognitive skills becoming encoded in procedural memory as a set of domain-specific “if...then” production rules. The productions specify under what circumstances a cognitive act is needed and what should occur (Anderson, 1982). A series of productions corresponds to the steps in a cognitive process for performing the task. The production rules are matched to the sensory data and content of working memory in order to modify working memory or

initiate motor output to enable performance in that situation (Müller, 1999; Taatgen, 2013).

Further practice can result in productions relating to sub-goals becoming collapsed together ('composed') to create a new production, making the processing faster and reducing errors. This also frees up working memory, which no longer needs to hold the declarative knowledge whilst the problem is being worked on. Each time a production is successfully applied it acquires strength and the strength determines the speed with which it can be used. Anderson contends that this strengthening mechanism follows the power-function speedup in skill performance. The model proposes a variety of modules which Anderson has mapped onto particular cortical regions and has been used to predict activity during an equation solving task (Anderson, Fincham, Qin, & Stocco, 2008). This theory is based very much on the computer programming metaphor.

This model has been further developed into the Acttransfer model based on the primitive elements theory (Taatgen, 2013) in order to accommodate and account for results of both near and far transfer experiments, in which the productions need to be applied to different stimuli from those on which they were formed. The primitive elements theory breaks down production rules into their smallest possible elements, which are mostly task-general rather than task-specific. There are a limited number of these PRIMs, related to comparing or moving pieces of information within the global workspace, and they are combined to build production rules. Some production rules may be task-general, others may be task-specific. There are also intermediate partial rules, which are task-general. Each person will form their own sub-set of task-general productions from all those available, which explains why individual performances can vary. The theory assumes that it is the development of

skills and strategies which enables transfer between tasks; if none of these overlap between tasks then transfer will not occur.

2.2.3 Instance Theory

Logan (1988) developed the instance theory of automaticity, which suggests that skill depends on automatic retrieval of stored instances from a domain-specific knowledge base; an instance having been stored each time the task is practised. This theory is item-specific and relies on the stimuli being consistent. Logan proposes that automaticity involves a shift from algorithm based processing to one-step retrieval from memory. He believes that encoding and retrieval occur automatically and unavoidably if some level of attention has been paid to the stimulus, although the amount of attention given will affect the precise details encoded. Thus all stored instances will not necessarily contain identical information, but the memory of all instances is activated whenever the stimulus is encountered. With sufficient instances the memory retrieval is faster and more reliable than computing the algorithm. The number of instances which is sufficient for the faster memory retrieval may vary depending on the task, and only a very few might be needed, particularly if the stimulus is memorable. Instances have to be encoded in such a way as to be easily and quickly accessible. This theory successfully accounts for the 'power law of practice' seen in practice learning studies. It does seem to require extensive numbers of memory traces, given the number of automatic processes and skills that are acquired during a lifetime.

Precisely what information is stored in an instance is unknown but Logan suggests that they comprise the goal to be attained, the stimulus, an interpretation of how that stimulus relates to the goal and the response which co-occurred at a specific time (Logan & Etherton, 1994). However, the co-occurrences are not represented equally within an instance (Logan, 1998). Instances must continue to be

accumulated, even after the stage of automaticity has been reached, and could therefore result in further improvements in speed or accuracy. Logan accommodates this by considering automaticity to be a continuum, in which properties appear at different rates, rather than an all-or-nothing process. Thus further speed improvements are possible, even after the switch to automatic processing has occurred, as shown in dual-task studies (Klapp, Boches, Trabert, & Logan, 1991). Other experiments have suggested that some attributes of a stimulus e.g. colour or location, may be encoded, but are not retrieved unless required, and that retrieval of attributes may take differing amounts of time (Logan, Taylor, & Etherton, 1996; Logan, 1998). Logan acknowledges that the instance theory has no mechanism to resolve interference in the case where similar instances, but with changed attributes, which require different interpretations or responses are retrieved (Logan, 1998).

Logan has tested his theory using tasks which require algorithmic processing and practice (e.g. the Alphabet Arithmetic Task) and with category search tasks. However he theorises that the notion of single-step direct retrieval from memory can explain a variety of automatic processes noted in the literature such as 'pop-out' effects in visual search, priming effects in lexical decision tasks, Stroop effects, sequential effects in serial reaction time tasks, and perceptual motor skills (Logan & Klapp, 1991). He suggests these processes can be explained by Instance theory if the difference between them lies in the memory system tapped.

2.2.4 Component Power Laws Theory

Rickard (1997) also developed a theory involving retrieval from memory, but proposes one 'prototype' memory representation, with distinct problem and answer nodes, rather than many separate instances and believes that only one retrieval can occur at a time. This then precludes retrieval of an instance and retrieval of any part of an algorithm occurring together, so that, unlike Instance theory, a strategy-choice

mechanism determines whether one-step retrieval or execution of the algorithm occurs. One consequence of this is that the switch to direct memory retrieval may not occur abruptly, but instead there may be a transition period when either retrieval or the algorithmic processing occurs, before the representation becomes strong enough for one-step retrieval to be used exclusively. The model therefore predicts that the power law holds separately for each component (algorithmic processing or memory retrieval), but not for the overall data. It also allows for a conscious choice to use the algorithm, if retrieval has failed. In an experiment involving an arithmetic calculation, post-individual problem probes demonstrated that participants were able to verbalise whether they used an algorithmic or retrieval strategy and that they moved from using one to the other during the practice. For some problems this was an abrupt change and for some it was more gradual, within the same person, i.e. memory retrieval was not implemented for all problems at the same time.

2.2.5 Reconciliation of procedural and retrieval models

Automaticity arises from practice learning, that is, repeated encounters with either the same stimuli which require the same response or a related set of stimuli which all require the same processing algorithm. The Production Rules theory and Instance theory do not have to be mutually exclusive – performance enhancements can arise from both declarative and procedural memory. In fact, Anderson et al. showed this occurs (1997) and that training circumstances affect which is the dominant process. Repetition of identical stimuli favours instance retrieval, which is considered to be faster than procedural retrieval, whereas stimuli which are similar but not identical favour the formation of production rules. Anderson et al. consider that performance in a skilled task reflects a complex mixture of processes, not just production rules and instance retrieval. Before these automatic processes develop the cognitive shortcuts used may involve creation of analogies and development of

abstracted declarative rules, although these are not definitive stages which are passed through (Anderson et al., 1997). Rather these are overlapping and intertwined, with non-automatic processes returned to if the task requirements change.

The above theories are data-driven, bottom-up processes. The theories which follow all involve some top-down processing, with strategies determining how the learned information is organised and retrieved. The long-term working memory theory considers how information in memory may be structured, whereas chunking is more concerned with the contents of long-term memory. Template theory brings together both of these ideas.

2.2.6 Long-term working memory

Ericsson and Kintsch (1995) proposed that individuals skilled in a domain overcome the limitations of short-term working memory for information by utilising long-term memory as a working memory. Items are stored in long-term working memory via a retrieval structure which enables ready access by relevant cues held in short-term working memory. This efficiently combines both short-term and long-term memory resources. They use this idea to explain both skills held by many people, such as reading, and skills that are possessed by just a few, such as trained exceptional memory for digit strings or medical expertise. The retrieval structure is rapidly modifiable if necessary, as shown by those who can recall very long and unique sequences of digits, and this indicates strategic and possibly conscious creation. As evidence for their theory, Ericsson and Kintsch summarise experimental results that concurrent memory tasks do not disrupt experts' working-memory and indicating that experts have complex structures in long-term memory. Long-term working memory is considered to be something which is domain-specific and which

develops over time as the skill is acquired through practice, although it does provide a means by which variable information from the domain can be stored.

2.2.7 Chunking

Chunking theory has developed from studies carried out in chess (Chase & Simon, 1973). Experiments with chess players of varying ability showed that perceptual processes and matching to acquired patterns held in long-term memory are the most important factors in distinguishing skill levels and this seems to be true in other domains as well. For instance, perceptual chunking can be seen in reading, where letters may be grouped into words or sentences. The chunking theory suggests that information about individual parts of a stimulus and their spatial relation to one another becomes aggregated, or 'chunked', resulting in the storage of patterns commonly encountered. Learning consists of the creation of these chunks, which in the case of chess can be from actual games played or those read about. The more expert players have a greater number of, and larger, chunks. Relevant chunks can be accessed and moved into working memory relatively quickly and either contain, or have links to, information about the best next move. One of the drawbacks with this theory is the capacity of working memory limiting the total amount of information that can be actively held at one time. Another problem with it is the large number of chunks which are postulated for the very best players – figures of 50,000 are estimated, although up to 100,000 has been speculated – and the theory does not specify how these might be organised for easy access, nor how such a database might be quickly searched to match with the current game being played. There is other evidence (Gobet & Simon, 1996a) that the figure of 50,000 is not excessive.

Newell and Rosenbloom (1981) suggest that chunks can themselves become chunked. Smaller sized chunks are used often, whereas larger ones are used more rarely and thus take longer to acquire, and they use this suggestion to explain the

power law. It is suggested that perceptual chunking is automatic (Gobet et al., 2001). Perceptual chunking does not seem to have been related to instance theory, although it is possible to speculate that a perceptual chunk is an instance, since chunks are co-occurrences of stimuli.

2.2.8 Template theory

Chunking theory has been combined with the long-term working memory idea to create template theory (Gobet & Simon, 1996b). This aims to explain some empirical results that highlighted shortcomings in chunking theory, for instance, findings that skilled players appear to hold more chunks than can be accounted for by models of working memory. In template theory, long-term memory stores a variety of information in several ways: firstly there are chunks containing around five pieces of perceptual information relevant to the domain (in chess this is the playing pieces); secondly there are templates, which are high-level schematic structures (in chess, a generalisation of one game board at a particular point in play) and finally there is a retrieval structure or structures which point to a sequence of templates. The templates are more elaborate than chunks and can contain semantic information as well as perceptual items. They are created automatically when learning mechanisms pick up frequently recurring patterns (Gobet et al., 2001), but can also generate links to form novel situations, such as new utterances from language knowledge. In chess templates might be familiar openings or lines of play, with certain pieces fixed, as they always occur in those positions, but with 'slots' where other variable information, for example from the current game, can be rapidly placed. Individual pieces or chunks can occupy a slot. Templates are implicitly acquired throughout the learning period and allow a player to choose their next move. Searching the networked templates is an efficient way to achieve this, by narrowing the choice of possible moves. Retrieval structures are deliberately and

consciously constructed to enable access to a number of templates and more than one can be held in short-term memory at a time. This theory has been specified enough to be implemented in a computer program, CHREST, which can simulate expert behaviour in chess, the learning of electric circuits in physics and syntactic categories in language as well as vocabulary acquisition (Gobet et al., 2001).

2.2.9 Summary

The various theories presented here have tended to come from different areas of practice learning. Theories of automaticity consider that the whole stimulus continues to be processed, but that either the ‘answer’ – for instance the word being read – is directly retrieved or the trace to the procedural knowledge is strengthened. Instance theory is based very much on experimental studies where the task is novel and a level of ‘skill’ can be obtained in a relatively short space of time, whereas chunking and template theory have been developed from studies of experts and intermediate players in chess, and long-term working memory was proposed from studies of exceptional memory feats. The Production rules theory considers processes not items and has developed from computer modelling studies. The theories do not need to be mutually incompatible – it is possible to conceive of different learning mechanisms for different types of tasks, which feed into different memory stores, and of further processes occurring, such as creation of templates, as skill develops into expertise.

2.3 DEVELOPMENT OF STRATEGIES

Theories such as Instance theory and the Production rules theory, advanced to account for how skill acquisition via practice leads to improved performance in speed and accuracy for both cognitive and motor tasks, are based on processing changes, increased efficiency in carrying out the steps of a task and increased

efficiency in performing sequences of components (Haider & Frensch, 1996). These changes have been referred to as qualitative (Haider & Frensch, 1996), reflecting the fact that the same stimulus attributes are processed but in a more efficient way. In addition, there is evidence that in some circumstances skill may be acquired or enhanced by application of strategies, which are non-obligatory, modifiable, top-down cognitive processes driven by existing knowledge and directed at achieving a goal. The retrieval structures posited for long-term working memory and template theory are considered to be strategically based, in that already stored knowledge about the domain is used in their creation, and they are also dynamically modifiable to accommodate current information.

Other performance-enhancing strategies reported as linked to practice learning could be broadly described as alterations to the task representation. The kinds of strategy noted in the literature include setting of response criteria and perceptual/attentional changes which enable salient information to be located quickly or less information to be processed. Altering the task representation may occur explicitly, for example from instructions given (Dreisbach & Haider, 2009), or may be implicitly learned from regularities in the task (Haider & Frensch, 1996). More detail about these strategies is given in sections 2.3.1 and 2.4. Explicitly or implicitly learned strategies acquired during practice may result in discontinuities in an individual's learning curve, as mentioned in section 2.1.2, and represent the point at which the strategy begins to be applied.

After outlining some of the reported strategies, the evidence around a strategy of reducing the amount of perceptual information, which is of particular interest to this research, will be examined in more detail.

2.3.1 Experimental evidence for the adoption of strategies

2.3.1.1 *Altering the task representation by instruction manipulation*

Some studies have deliberately set out to alter the task representation by changing the instructions given. Dreisbach and Haider (2009) found evidence that manipulating task representation in this way could result in the ignoring of irrelevant information. They used a Stroop-like task with words superimposed on semantically related or unrelated line drawings, with the added complexity that the drawing could provide an additional clue as to the response key required. Some participants were provided with a rule which simplified the learning of the relevant response key, in other words an easier task representation, and these performed faster when there was a semantically unrelated distracter. The same effect was seen when participants in the harder task representation group were first given practice without the distracters, in order to learn the stimulus response mapping. Dreisbach and Haider took this to indicate that a strategy of ignoring irrelevant information was formed by those with the easier task representation or those who had learned the key-mapping first, directing attention to selectively focus on the word.

2.3.1.2 *Setting response criteria*

In many practice learning studies participants are instructed to respond as quickly and accurately as possible as development of skill is determined by improvements in speed and accuracy. However, the conditions of the task may encourage either speed or accuracy to dominate the responses, in other words the task representation develops so there is a speed-accuracy trade-off. Strayer and Kramer (1994a) used a memory search task where participants were trained with either blocks of consistently mapped or variably mapped stimuli or with blocks of

mixed stimuli. They found that if the mapping was always the same separate strategies arose – consistently mapped stimuli were responded to more quickly but less accurately whereas variably mapped stimuli were responded to more accurately and more slowly. In the mixed blocks no strategy arose and this gave intermediate speed and accuracy. These strategies of changing the response criteria would appear to have developed implicitly. In test blocks the developed strategies were appropriately deployed depending on the stimulus type.

Strayer and Kramer concluded from their series of experiments that data-driven learning is stimulus specific, automatic and continuous whereas strategic learning can be transferred to a new set of stimuli, provided they are encountered under the same stimulus-response conditions. They suggest that adoption of a performance-optimising strategy occurs early in training and that it is hard to adjust this strategy or find a new one at a later time. Even giving a cue prior to stimulus presentation was not enough to enable strategy adjustment, trading speed for accuracy, once training had taken place, although Strayer and Kramer feel that other strategies may be dynamically modifiable (Strayer & Kramer, 1994b).

In other studies the effect of altering the instructions to emphasise either speed or accuracy has been shown to alter the adoption of the Information Reduction strategy, in which irrelevant information is ignored (Haider & Frensch, 1999b). Haider and Frensch found that more Information Reduction was seen with instructions to optimise speed, and with reductions in time available to respond, and less Information Reduction was evident with instructions to be as accurate as possible.

2.3.1.3 *Perceptual changes*

Practice can alter the task representation of how to perceive the stimuli – either to move away from attending to all individual features to holistic processing, or to move away from processing all individual features to only some of them. The latter has been referred to as a quantitative change (Haider & Frensch, 1996). It has been noted in the expert-novice literature that experts attend to visual information in a different way to novices e.g. experienced players of the video game Space Fortress (Mané & Donchin, 1989) eliminate repetitive saccades to previously processed or irrelevant stimuli and use peripheral vision for some object analysis (Shapiro & Raymond, 1989). Shapiro and Raymond also demonstrated that it was possible to train novices to make use of these eye-movement strategies and thereby improve their performance.

2.3.1.3.1 *Holistic processing*

Expertise can result in a shift from a featural search to holistic processing. Kundel et al. (2007) carried out an eye-tracking study with expert and less well-practised mammographers, finding that the experts were faster and more accurate at locating suspected lesions. They concluded that this was due to a rapid holistic processing enabling identification of areas needing closer examination combined with an extensive knowledge of the characteristic features of normal and abnormal x-rays. This strategy appears to be both implicitly learned and implicitly applied.

Holistic processing has also been invoked as an explanation in some cognitive experiments involving stimuli novel to all participants, rather than expert-novice studies. Bethel-Fox and Shepard (1988) tested participants on mental rotation of 3x3 matrices with some filled-in squares. They found that stimulus complexity effects, whereby processing of matrices with more squares to encode took longer than those

with fewer, were eliminated after practice. They attributed this to formation of internal representations of the practised stimuli which could be rotated holistically.

Pellegrino, Doane, Fischer and Alderton (1991) also attribute the increased speeding found for more complex stimuli, in a same-different judgement task involving irregularly-shaped polygons with the number of vertices varying from 6 to 24, to the development of holistic stimulus representations as practice proceeded. These representations could then be rapidly compared with other stimuli.

2.3.1.3.2 *Processing less information*

An early example of a strategy of ignoring irrelevant information occurs in the second part of the paper by Schneider and Shiffrin (1977), which investigated controlled and automatic processes. In experiments 4a-4d, participants were told to attend only to certain locations and to respond to certain stimuli. They practised this for a number of trials and were able to obey the instruction to attend selectively to part of the overall stimulus. On later trials some of the stimuli appeared elsewhere, although the participants were still supposed to be attending to the specified area. It was found that if the trained stimuli were placed in an alternative location the participants automatically responded to them, thereby showing distraction. Although this was not a skill-acquisition task, it nonetheless demonstrated that perceptual adjustment is possible. The strategy was learned under explicit instruction and consciously applied.

Haider and Frensch (1996) claim to be the first to apply the idea that a strategy of ignoring irrelevant information could be found in the field of skill acquisition. To investigate this, they developed the Alphabet Verification task, a cognitive task with stimuli which are novel to the participant at the start of training. The Alphabet Verification task will be elaborated upon in Chapter 3 and the various experiments which have been performed are outlined in section 2.4. Information Reduction

seems to be a strategy which is learned implicitly, although it may become available to conscious awareness.

Other experimental evidence for a strategy of only processing some parts of a stimulus exists. Doane, Sohn & Schreiber (1999) built on some earlier work they had carried out using the same task and stimuli as Pellegrino et al. (1991). It had previously been concluded that different strategies were adopted depending on the difficulty of the training set and that although a developed strategy was stimulus-driven it was not stimulus-specific (Doane, Alderton, Sohn, & Pellegrino, 1996). In the 1999 study, participants were also given a recognition test for individual encountered polygons following training. The idea behind this was that if participants had conducted an exhaustive search when making their comparisons then the polygons would be more familiar than if the same/different judgement had been made on a small number of features. Doane et al. concluded from their results that participants trained with polygons that were hard to discriminate started with an exhaustive search which developed into a strategy of limiting their search to features they had learned were relevant to the task, whereas participants trained with easily discriminable stimuli did not change their initial strategy of an early terminating and unconstrained feature search. In other words the strategy which produces the most accurate results more quickly becomes adopted. It was necessary for participants to learn, for each of the presented polygons, which of the features were the relevant ones, in order for this Information Reduction-like strategy to be used, and this information would be stored as part of the instance. Doane et al. do not report asking participants how they had gone about the task, to see if the strategies are verbalisable and thus available to conscious awareness. Also it is not clear if they consider the inferred Information Reduction-like strategy to be conscious or

unconscious. Nor is it possible to deduce, from the reported aggregated results, whether all participants in either condition used the attributed strategy.

Using eye-tracking in the Kanfer-Ackerman Air Traffic Controller Task, Lee and Anderson (2001) demonstrated that learning to ignore irrelevant information accounted for 85% of the speed-up observed over training, and that the separate unit-task improvements fitted a power-law function. The Air-Traffic Controller Task is a simulation in which participants are required to land planes taking into account various factors. These include wind speed and direction, length and condition (wet or dry) of runway, how recently another plane has landed on that runway, type of plane and remaining fuel load. It is a complex task with a great deal of information on the screen, so only fixating on relevant information would seem to be a useful strategy. Lee and Anderson note that participants did not mention in post-task questioning that they fixated less on irrelevant portions of the screen and speculate that this was due to a lack of awareness of so doing. However, this could be due to the nature of the question, which appears to have been very general. They also discuss the possibility that improvements in different parts of the task are due to different mechanisms, suggesting that selecting a procedure (as with Instance theory (Logan, 1988)) strengthening a procedure (as with Anderson's (1987) Production rules theory) and transforming a procedure (as in Newell and Rosenbloom's (1981) chunking theory) may all be occurring.

2.3.1.4 Summary

As can be seen a number of different strategies have been reported in the skill acquisition literature, many of which depend on the precise representation which forms before or during the skill acquisition phase. Task instructions can not only directly affect the representation but also can interact with a developing strategy. It seems that both stimulus-specific knowledge and development of strategies are

important, at least in some domains, in practice learning. Not only this, but evidence that strategies are transferable and not item-specific, indicates that use of a strategy can enhance performance when new, but related, stimuli are encountered within a domain. However, other evidence, which will be presented in section 2.6.1, suggests that not everyone may develop or apply a strategy. Factors which affect whether one particular strategy or another, or no strategy at all, is developed or used need to be explored. One such factor is individual differences (Schunn & Reder, 2001), processing differences between groups of people which arise either directly or indirectly, for example from differences in working memory capacity or personality factors. The effect these may have on whether a strategy is learned, applied or possibly modified is examined in section 2.6.

Before the effects of individual differences are discussed, the various experiments used in examining Information Reduction will be detailed, followed by the hypothesis about the mechanism derived from these experiments.

2.4 THE ALPHABET VERIFICATION TASK

The Alphabet Verification task involves verifying an alphabetical string where a number indicates letters to be skipped in the sequence and is explained in more detail in Chapter 3. In training the letter immediately following the triplet is either correct or is replaced by the next following one in the alphabet, making it incorrect. After a number of training blocks with the error always in the same place, a test block is administered in which the location of errors is occasionally in the trailing letters, an ‘irregular’ string. If participants are ignoring all but the triplet then they will incorrectly verify these strings, i.e. they will display negative transfer where the characteristic of the task is slightly altered.

Examples of strings are:

correct string	D[4]I J K L	there are 4 letters missing
incorrect regular string	D[4]J K	there are 5 letters missing
irregular string	D[4]I K L	the 'triplet' is correct but J is missing from the trailing letter string

The various experiments which have been carried out to investigate Information Reduction with the Alphabet Verification task will now be outlined.

2.4.1 Findings from the initial experiments and later confirmations of item-generality

Initially Haider and Frensch (1996) conducted three experiments using the Alphabet Verification task. The measures they used were the 'string length effect', where the RT varies with the length of the letter string, and the error rates when irregular strings were presented in the test block (see Chapter 3 for a fuller explanation of these). They found that:

- Information Reduction occurs whether or not specific instruction about relevance is given. In other words the learning can be incidental.
- more Information Reduction occurs with longer training
- Information Reduction transfers to a new set of related stimuli, indicating that it is an item-general strategy.

A later experiment by Haider, Frensch and Joram (2005) repeated this item-generality finding, using a greater range of triplets (8 starting letters in each set, as opposed to 5 in the 1996 study). RTs increased with this new item set, and this does tend to rule out Anderson's Production rules theory as contributing significantly to this task. Being item-general it could account for the transfer, but it would predict

that the improved algorithmic processing should transfer without significant loss of performance. The increase in RT suggests that participants had to revert to the counting-through-the-alphabet algorithm instead of retrieving instances, exactly as Instance theory would predict. However, the string length effect did not return, indicating that the trailing letters were still ignored and this indicates either that instance learning is not the sole process operating or that it is not used.

Item-generalizability was also demonstrated in a later experiment (Gaschler & Frensch, 2007) which varied the frequency of presentation of the strings. It was found that Information Reduction developed at the same time for both the frequently presented and the infrequently presented strings. It is hard to reconcile these findings with Instance theory, which states that the more frequent the encounter the more instances become stored and the more likely it is that memory retrieval will be faster than computing the algorithm, and therefore would predict that the same number of encounters would be needed for each string for its processing to become automatic.

It is likely that memory for specific triplet instances does play a part in the Alphabet Verification task, since it is performed significantly more quickly and accurately even when just the triplet is presented and Information Reduction is not required (Experiment 1, Haider & Frensch, 1996). This then makes it probable that Information Reduction occurs in conjunction with Instance learning in the Alphabet Verification task, although this does not mean that the two have to co-occur in all tasks. Another possibility is that a combination of Instance learning and composition of production rules could account for these results, and that it is not necessary to invoke a new mechanism. However section 2.4.2 outlines other results which cannot be explained by a combination of the two automatic learning processes.

Haider and Frensch treat each of their 50 correct and 50 incorrect strings as unique instances, so that D[4]I, D[4]I J, D[4]I J K are all different. However, it is not known if they are processed as unique instances. Participants may segment the strings into triplet part and trailing letters, in which case they only have 10 unique correct and 10 unique incorrect triplet instances, or even less in some experiments. Additionally, Logan himself is not clear what is in an instance and whether only identical instances are activated. So, for instance, the stimulus D[4]I J K will activate itself, but does it also activate any other related form e.g. D[4]I, D[4]I J? There would have to be a degree of parallel, not serial, processing of the elements of the stimulus if intermediate ‘stages’ are not activated, which tends to suggest that the stimulus must be processed holistically so that length of string would not affect processing time after automatization. Haider and Frensch do consider that similar instances might be activated, as it could explain the attenuation of the string length effect. The issue of what constitutes an instance is still to be resolved, but even if Instance theory can explain the reduction in the string length effect, it cannot explain the lack of string length effect on transfer to completely new instances.

One of the assumptions Haider and Frensch make is that all participants process each element of the string in a linear left-right fashion, giving rise to the string length effect. However, this is not necessarily the case, as suggested above and as seen in Haider and Frensch’s 1999 data where they noted “*unexpectedly flat slopes*” on the aggregated data in the first training block (Haider & Frensch, 1999a, p177). This could be connected to the trailing letters being processed as a ‘chunk’ by some or all participants, rather than separately. Whether or not this happens may depend on an individual’s internal representation of the alphabet. Whatever the reason, it seems sensible to develop other tasks that do not make use of a well-learned and oft-used sequence. Another issue with the Alphabet Verification task is that it takes

around 500 trials for Information Reduction to develop and this means the participants are required for an hour or more. If possible, it would be useful to employ a task in which Information Reduction developed more quickly, although Doane et al. (1999) used 960 trials in their polygon discrimination task and this may mean that Information Reduction does not develop without a large number of repeated exposures to the stimuli.

The initial set of results showed that the string length effect attenuated over practice, that there were an increased number of errors in the test block due to irregular strings being categorised as correct and that the process transferred to novel but related stimuli. It was deduced that there may be an Information Reduction strategy in use. The full set of results cannot be explained by Instance Theory or Anderson's Production rules theory acting alone, although conceivably a combination of the two might account for the observed effects. It seems most probable that instance learning and Information Reduction are operating in combination in the Alphabet Verification task, but it is not clear if all participants are carrying out the task in the assumed way. Some could be using other strategies, for example making use of already existing internal representations of the alphabet, and this may be an unconscious strategy. Using other tasks may prevent this surmised alternative strategy, although it should be borne in mind that other strategies may replace it.

2.4.2 Later experiments

Haider, Frensch and colleagues have carried out a variety of experiments in which they manipulate aspects of the Alphabet Verification task, in order to test if the Information Reduction they had deduced was due to the characteristics of the task. They suggest that this is an alternative to devising new tasks, which they consider would be subject to methodological difficulties in measuring Information

Reduction directly (Haider & Frensch, 1999a). However Information Reduction is inferred from the attenuation of the string length effect and an increased number of errors in the test block in the Alphabet Verification task, so this argument seems somewhat spurious. Doane et al. (1999) also use the decline in regression slopes for stimulus complexity to measure their Information Reduction-like strategy, finding this was significant in their difficult-discrimination group, but not the easy discrimination group. This therefore does not rule out using other tasks in which Information Reduction is inferred in this way.

2.4.2.1 *Stressing either speed or accuracy*

In a second set of experiments Haider and Frensch demonstrated that changing the instructions to stress either speed or accuracy affects the extent of Information Reduction occurring, with Information Reduction being adopted more quickly under speed stress (Haider & Frensch, 1999b). They conclude this shows that people can modify their behaviour to some extent. In other words, that ignoring redundant information is a strategy that is, at least partly, under voluntary control, with participants choosing to use the strategy under speed instructions but choosing not to use it under accuracy instructions, or at least making a conscious decision to check the whole string in the accuracy conditions, over-riding the reduction process. Other research (Hoyndorf & Haider, 2009) indicates that being given accuracy instructions can cause participants to inhibit fast responses which might occur as a result of an implicitly learned process. This was termed ‘not letting go’, and ties in with what is seen in other fields, such as emotional psychopathology and addiction, where conscious over-riding of automatic processes is needed to overcome attentional bias to salient stimuli (Williams, Mathews, & MacLeod, 1996).

It has been suggested that speed stress can increase the rate at which a task becomes automatic (LaBerge & Samuels, 1974). If this is the case most of the results

reported by Haider and Frensch, where the responses become faster more rapidly under speed stress, do not rule out either Logan's or Anderson's theories of automaticity, although Haider and Frensch take them as indications that the Information Reduction strategy is under conscious control.

One thing that Haider and Frensch do suggest is that under speed stress the participants may not have been 'reducing' by processing only the triplet but may have been reducing by randomly sampling parts of the string to determine their response, which would have decreased their accuracy. This remains something to be tested. Post-testing questions or protocol analysis might provide some insights into any conscious knowledge, but probably eye-tracking would be more effective to determine where participants are fixating and for how long. Verbalisation not only assumes that participants are conscious of the processing carried out, but that they are able to articulate it and that they include all relevant detail. Eye-tracking is a direct measure of behaviour, although it cannot be assumed that fixated items are necessarily fully processed or that non-fixated items are not processed (Shapiro & Raymond, 1989).

It is known that people can consciously alter their response criteria depending on the demands of the task, being more liberal and checking less when the need is to be fast, at the expense of accuracy. This would seem to be borne out by Haider and Frensch's results for experiment 1, where a large number of participants in the speed condition (15/41) were excluded from the analysis due to making more than 15% errors. A slightly smaller proportion was excluded from the speed-accuracy and accuracy-speed conditions (9/40 and 8/41 respectively) but no data was given as to whether the errors were spread through all blocks or occurred predominantly in the speed-stress ones. This is in comparison with 3/45 being excluded in the accuracy condition and also in comparison to using a 'cut-off' of 10% errors in other

experiments. That is, more participants may have been excluded from the analysis with the stricter cut-off. On the whole the participants left in the analysis did not show a reliable speed-accuracy trade-off, although the correlation was significant during the speeded blocks in the speed-accuracy and accuracy-speed conditions.

In experiment 2, where the speed stress involved the strings being visible on screen for a reducing amount of time as well as instruction manipulation, 13/21 participants were excluded in the speed condition for more than 15% errors, 8/21 and 5/21 in the speed-accuracy and accuracy-speed conditions and just 1/20 in the accuracy condition, where the strings were on screen for 6 seconds throughout the experiment. The relatively high numbers of people making more errors when under speed stress does bring into question the types of strategy, if any, being employed and does strongly suggest that the excluded participants were showing a speed-accuracy trade-off, which is an another valid strategy.

It is not clear from Haider and Frensch's results (1999b) whether more participants used the Information Reduction strategy when under speed stress, or if it were just that those who did adopted Information Reduction more quickly. There is a slight indication in the 2005 experiment (Haider et al., 2005) that more might use the strategy, as this used short speeded blocks between the main training blocks and reports 63% of participants in the Always-regular condition using Information Reduction, as judged by a drop in RT of 1second between blocks. This compares to 40-50% reported users in other experiments, although in these Information Reduction was measured by the more standard methods of attenuation of the string length effect and increased errors to irregular strings. A large change in RT is suggestive of a strategy being employed but does not indicate which strategy. Therefore further experiments are needed to try and distinguish what the participants are doing – do the same proportion use Information Reduction as in experiments

where both speed and accuracy are instructed, but perhaps in conjunction with a faster development of triplet memory; do some of those who have not become aware of the regularity use a speed-accuracy trade-off instead; or do more participants use Information Reduction? A first step towards distinguishing these possibilities would be to determine how many seem to be using Information Reduction under speed stress and to examine whether there is a speed-accuracy trade-off for participants who do not seem to be using Information Reduction.

In this experiment, in contrast to many others, no trial-by-trial feedback on errors was given and since there had been no published work investigating the effect of this on the development of Information Reduction, it is possible that the results are confounded by the change to this variable.

2.4.2.2 *Triplet position and duplicating information*

Haider and Frensch have shown that Information Reduction occurs whether the triplet is positioned at the beginning (relevant-first) or the end (relevant-last) of the string, or even if training contains both triplet positions presented randomly (Haider & Frensch, 1999a). By the end of the training the slopes had not declined as far in the relevant-last or mixed conditions as in the relevant-first, but by the measures used Information Reduction was still inferred to be occurring. This goes some way to showing that Information Reduction in the Alphabet Verification task is not an artefact of the left to right reading seen with Latin alphabets and that the relevant information does not have to be encountered first for Information Reduction to occur. It also suggests that an early terminating feature search strategy is not in use, as this would require the whole string to be processed in training in the relevant-last condition, whether it was correct or incorrect. This experiment gives the first indication in the literature that not all participants use the Information Reduction strategy. For those who received no feedback in the test block a

scatterplot of mean regression slope over the final two training blocks against error rate for irregular strings suggests that some completely reduce, some do not at all and some are perhaps variable in their usage. In the relevant-first condition 41% were classified as reducers, with 52% classified as reducers in the relevant-last condition. Haider and Frensch do not comment on possible reasons for this differential use of Information Reduction. Since they hypothesise Information Reduction to be a general learning process it must be assumed to be available to all and therefore the question arises of why usage varies between, and possibly within, participants.

An alternative transfer experiment to those described in section 2.4.1 would be to train participants with the triplet in one position and then given the other positioning in the test block. This does not seem to have been carried out, neither do other transfer type experiments, such as changing the nature of the stimuli or keeping structurally similar stimuli but changing the ‘rule’ about what is relevant. Transfer experiments such as these could yield valuable information about whether an Information Reduction strategy is in use and its conscious nature.

A similar set of experiments to the triplet position ones of Haider and Frensch were carried out by Green and Wright (2003) in which there were relevant-first strings with errors in both the triplet and the post-triplet letters, relevant-last strings with errors in both the preceding letters and the triplet or reversed relevant-first strings, again with errors in both parts of the string, in training, but with errors occurring in only one place in the test block. In other words, there were two sources of information as to whether the string was incorrect in training. Participants in the reversed string condition were instructed to read from right to left, although it is not known if they were able to consistently follow this instruction, which would have required conscious effort to overcome the automated left-right reading process.

Results indicate that participants tended to reduce to one source or the other, in general choosing to use the one encountered first in the reading order. This is indicative of Information Reduction occurring at the perceptual level and is evidence that there is more occurring than the automated whole stimulus processing of Logan and Anderson. However, the decline in the string length effect and particularly the error rate results suggest that some participants chose the second source processed, or possibly alternated between which source they would use. This latter possibility is not considered in the paper, nor is it possible to deduce from the results given whether some participants did not reduce at all.

Aggregated data always conceal what is happening on an individual level and later experiments confirm what was found in the triplet position varying experiments, i.e. that not all participants discover or use the Information Reduction strategy (Haider & Frensch, 2002; Haider et al., 2005). Thus it seems likely that this is a common feature of all reported Alphabet Verification task experiments. However, a small-scale experiment with six participants (Haider & Frensch, 2002) indicated that length of training may be a factor in whether Information Reduction is discovered and used, with the usual 500 training trials being insufficient for some. Nonetheless it could be the case that some would never discover the strategy however much training they received.

2.4.2.3 *Eye tracking*

Haider and Frensch (1999a) used an eye-tracking experiment, with the standard Alphabet Verification task instructions, which indicated that participants were ignoring the redundant information at the perceptual level. Fixations were still made on the redundant portions of the string but there were fewer of them. Also they were of shorter duration than the fixations on the relevant portions of the string. The fixation frequencies predicted the attenuation of the string-length effect –

participants who fixated less on the irrelevant information showed the smallest string-length effect, thus suggesting that they were not perceiving or processing the redundant trailing letters. The experiment involved the strings being projected onto a large screen and it is hard to calculate from the information given precisely the difference between using a normal monitor and the screen. It appears that the visual angle required to perceive a whole 7 letter string would have been more than twice as much as with a computer monitor, which would have necessitated more eye-movement. Therefore the participants may have been more inclined to fixate only on the relevant portion, in order to minimise effort, and this means that it may not be completely valid to generalise to experiments conducted on a monitor.

Haider and Frensch do note that part of the strategy may be to minimise the time spent fixating on the redundant information if it is not possible to completely ignore it. Again this would need to be a conscious decision and better tracking of eye movements may pick this up. The Information Reduction hypothesis (see section 2.5) is based on perceptual changes, which neither Logan's (1988) nor Anderson's (1987) theories predict, and this part of the hypothesis essentially rested on the results from this one experiment. Given the importance of conscious perceptual changes to the Information Reduction hypothesis, replication of this eye-tracking experiment is required. However, it should be borne in mind that eye-tracking can only indicate what is being fixated and for how long and not what is processed, nor whether any conscious decisions as to what to fixate are being made.

This eye-tracking experiment was another in which no trial-by-trial feedback was given, without explanation as to why, and the effect this might have had is unknown. The effect of varying the type of feedback, or even giving none at all, is something which could be investigated. If reinforcement occurs after a trial in which

irrelevant information was ignored, then this might encourage the further use of the strategy and would confirm its theorised conscious nature.

More recently another eye-tracking experiment has been carried out (Gaschler et al., 2015), using a computer monitor, although again the visual angle for the strings was wider than would normally be used, with the longest strings spanning the whole screen of a 17" monitor. A variation on the 'normal' Alphabet Verification task was that brackets were not included in the string, so that the relevant portion may have been less obvious (see section 2.4.2.5 for the effect of lack of segmentation in a different task). This variation was not deliberately introduced by the authors (Gaschler, personal communication, 2016). Strings were either presented three times per block (frequently), once per block (infrequently) or just twice overall (singletons). In this experiment feedback was given on incorrect responses during the training blocks. Results showed that the average fixation time on the irrelevant portion of the string decreased at the same rate and to the same extent regardless of the frequency of encounter, providing further evidence for the item-generalizability of the strategy. Results also showed that some participants adopted the strategy abruptly, whereas this did not seem to be the case for others, and that whilst some participants were reducing from the first practice block, others needed over 400 trials. This points towards individual differences between participants.

2.4.2.4 *Inconsistent training*

The final experiments to be discussed differed from all the preceding ones in that a small proportion of irregular strings appeared in the training blocks. It was argued that by showing if a degree of inconsistency prevents Information Reduction from developing, evidence for its conscious nature is provided, i.e. that if the rule is sometimes broken, then a decision is made not to rely on it. However, without knowledge of the mechanism by which relevant information is distinguished from

irrelevant, it could be that even a small degree of inconsistency prevents knowledge of any regularities developing. Haider, Frensch and Joram (2005) go some way to addressing this latter criticism by incorporating some speeded trials containing only regular strings between the training blocks, and these show that those in the 90% regular condition performed at the same level as those in the 100% regular condition. They took this to mean that the strategy was learned and could be applied when speed pressure dictated it was more efficient, but was not used when more time was available. However, they used a drop in RT of more than 1second between training blocks as evidence that Information Reduction had been adopted, which only really indicated that some sort of strategy was in use, and do not relate this to individual performance in the main training or the speeded blocks. The high error rates seen in the test block could be due to a speed-accuracy trade-off strategy being applied. Perhaps a better indication of a conscious decision not to rely on the regularity was demonstrated by Edmunds (2005), who used a similar experimental procedure, where post-testing questions revealed that the same number noticed the regularity in the 90% regular condition as the 100% regular condition, but the regression slopes did not change significantly over training for the former condition as they did for the latter, indicating that the potential for Information Reduction was known but it was not used.

Gaschler and Frensch (2009) varied the presentation frequency as well as having some irregular strings in training. When the irregular strings were in the less frequently presented set, Information Reduction continued to develop for both sets and when they were in the more frequently presented set, Information Reduction did not develop for either set. If Information Reduction was dependent on the number of encounters with an individual stimulus, as Instance Theory would predict, then this cross-set transfer should not occur and so this is further evidence that a separate

mechanism was in use. When the irregular strings were presented in the less frequently encountered set, this was at a rate of 8% of incorrect strings per block, which answers the criticism that any inconsistency will prevent Information Reduction from occurring. Therefore it seems that there is a threshold roughly between 8% and 10% irregularity, when a significant number of people will cease to rely on knowledge of the regularity and this perhaps needs to be explored in more detail and at an individual level, since it may be important to know for an individual the point at which they can be prevented from developing Information Reduction.

2.4.2.5 *Task variations*

At the start of this study, the only alternative task used to investigate Information Reduction which I was aware of was the target search task developed by Edmunds (2005). In this task, participants are required to indicate if one of three letters in a memory set is present in a variable length string of randomly ordered letters. In training the target always appears in the same position in the string, when it is present. Edmunds carried out a number of manipulations using this task. He demonstrated that Information Reduction occurred when all the strings were unique, thus ruling out instance learning as an explanation. He also showed that increasing perceptual load, by increasing the length of the strings, caused more participants to be aware of Information Reduction. Other manipulations were: using brackets to segment the string into relevant and irrelevant sections (as is seen in the Alphabet Verification task); increasing difficulty by requiring participants to indicate if the letters adjacent to the target came before or after it in the alphabet; and using a limited number of relevant section instances. These manipulations resulted in lower regression slopes at the end of training than occurred with the basic task and all but the segmentation of the strings also caused an increase in errors to the irregular strings in the test block. In addition more participants expressed explicit knowledge

of the regularity suggesting that Information Reduction was used by more participants when attention was directed to the part of the string where the regularity occurred and when using the strategy released cognitive resources to deal with an additional demand. Edmunds does not differentiate between knowledge and use of the strategy. Having a limited number of instances in the bracketed section was the most effective and this strongly suggests that instance learning of the relevant part of the string was partially responsible for the results seen.

Recently another Information Reduction task has been introduced in the literature (Gaschler et al., 2015), which required participants to indicate whether there were an odd or even number of instances of a letter randomly scattered over the screen. The rationale for this parity judgement task was to test whether it was the spatial positioning of the triplet in the Alphabet Verification task which induced Information Reduction. The regularity for the new task was that whenever the number of instances of the letter was above four it was always either an odd number, for half the participants, or always an even number, for the other participants. In the test block the irregular trials had the number of instances above four as even for those with the ‘odd’ rule and odd for those with the ‘even’ rule. As with Gaschler’s other experiments, there were frequent, infrequent and singleton trials in each block. Results showed a gradual decrease in processing time with practice and that some participants had an abrupt change in performance for all stimuli regardless of the frequency of presentation, although 19% did not appear to discover the shortcut at all. Whilst Gaschler et al. used letters in this task, it could equally well be performed with shapes or other stimuli types.

2.4.2.6 *Comparison of tasks used*

Both the Alphabet Verification task and the polygon-matching task (see section 2.3.1.3.2) have led to conclusions about a strategy involving processing of

only part of the stimuli. However, there are some differences between them in features of the tasks and the theoretical explanations invoked. In the polygon task the relevant features vary from polygon to polygon, so that it is necessary to learn which features to process for each item. Indeed, different individuals may choose different features. Doane et al. (1999) suggest that instance learning is important for this task as well as using an Information Reduction-like strategy but that on transfer participants revert from retrieving specific instances to use of more general strategic skills. Transfer to novel hard stimuli was positive where an Information Reduction-like strategy had developed and negative where an early terminating feature search had developed. On the other hand, the Alphabet Verification task always has the relevant information in the letter-digit-letter triplet in training and on transfer to novel stimuli, the target search task always has the target in the same position and the parity-judgement task always has the large sets as either odd or even. That is to say, there is always a consistent rule which indicates which information is irrelevant and can be ignored. Haider and Frensch believe that the item-general transfer seen with this task indicates a conscious decision to limit processing to the relevant elements of the stimulus and base their hypothesis of Information Reduction on this.

All these different types of tasks indicate that a strategy in which fewer elements of a stimulus are processed occurs in some practice learning tasks, and this ties in with other empirical evidence that not everything in a visual scene is processed.

2.4.2.7 *Post-testing questionnaires*

In some Alphabet Verification experiments the participants have been asked post-testing about characteristics of the strings they have noticed and around half report that the error always occurs in the triplet (Haider et al., 2005), with the majority of these appearing to use the Information Reduction strategy (Haider &

Frensch, 1999a). This tallies with the experimental data, and suggests that using post-testing questionnaires may be a reliable method of distinguishing reducers from non-reducers.

All apart from one participant in the parity judgement task (Gaschler et al., 2015) were able to verbalise the regularity in the task, but there were some participants who did not appear to exploit it, and carried on counting the letters in the display. Interestingly, Edmunds (2005) also found that all apart from one participant were able to express the regularity in the target search task when longer strings were used, which suggests that when a variable and larger amount of processing is required then people will endeavour to find ways to reduce the burden. Edmunds also demonstrated that other manipulations increased the number of those aware of the regularity, although this was not to quite the same extent. However, it does seem that numbers using Information Reduction can be altered with changes to training conditions.

2.4.2.8 *Summary of experiments*

The experiments outlined here indicate that Information Reduction involves a change at the perceptual level, which cannot be explained by either Logan's (1988) or Anderson's (1987) theories of automatic processing, or even a combination of both. The strategy seems to be data-driven but can transfer to new instances of the stimuli. Evidence also suggests that it is a consciously applied strategy. It would appear that strategies may be important in skill acquisition, but the theorised processes behind strategy development are still not well specified. In addition, it is noted that variations in adoption of the strategy may occur. These could be due to other strategies being used, individual differences in participants or differences in task or training conditions. For instance, Information Reduction seems to be sensitive to the level of consistency encountered during training. It may be supplanted by other

strategies, such as a speed-accuracy trade-off, under some conditions. What is not clear is if all people are capable of discovering and using the Information Reduction strategy but, for as yet unknown reasons, choose not to use it, or whether it is not available to all. Indeed it is possible that some may be unable to verbally express knowledge of a regularity, but that Information Reduction is still used. Manipulating both type of task and the training conditions offer promise as a way to explore the numbers of people using Information Reduction and perhaps determining whether people use it sometimes and not at other times.

2.5 THE INFORMATION REDUCTION HYPOTHESIS

Experimental results from the Alphabet Verification task indicate that the Information Reduction strategy can be transferred to novel, or less frequently encountered, stimuli (Gaschler & Frensch, 2007; Gaschler & Frensch, 2009). This indicates that the strategy is item-general and does not depend on instances being retrieved from memory. The item-generalizability suggests that theories such as the Instance model of Logan (1988) cannot fully explain the processes occurring. Anderson's Production rules theory cannot account for the conscious aspects of the process, and neither theory can account for the perceptual differences that have been noted. This led Haider and Frensch to propose the Information Reduction hypothesis, with two stages: a data-driven, implicit stage in which relevant and irrelevant information is distinguished; and a consciously applied stage in which only relevant information is perceived and processed.

Haider and Frensch believe that Information Reduction is a general and non-domain-specific learning process which is strategically applied, rather than an inevitable consequence of practice and that it may operate in addition to other learning mechanisms such as Instance theory. Although the switch to using Information Reduction is thought to occur abruptly, rather than gradually, the fact

that it occurs at different times for each individual means that when the learning curves are aggregated, the normal power law is seen. The various results obtained since the Information Reduction hypothesis was proposed do fit with this model, however, the evidence suggesting that it is a consciously applied perceptual strategy is not strong and there are alternative explanations.

There are also questions about whether Information Reduction is a general learning process. It has only been noted in a small number of tasks, and results from manipulations of just one of these, the Alphabet Verification task, have been published. It is still possible that the results Haider and Frensch obtained are simply due to characteristics of the Alphabet Verification task itself. If this two-stage Information Reduction process does exist, then presumably the data-driven stage is common to all. A question then arises as to why only some people appear to become aware of there being redundant information and are able, or choose, to implement the strategy. In order to investigate this further, the number of people using Information Reduction in both the Alphabet Verification task and other tasks should be determined, as well as those who choose not to use it. For some people it could be that some mechanism, unconscious or conscious, suggests that they can gain just as much improvement, or at least a 'good enough' improvement, by merely learning stimulus-response associations, as Instance theory would suggest happens inevitably, or by using another strategy. If the numbers using Information Reduction can be established then a variety of manipulations can be carried out to examine if the number of users can be increased or decreased. In particular, if conditions under which all participants use Information Reduction can be found, then this will provide stronger evidence that it is a general learning mechanism.

2.6 INDIVIDUAL DIFFERENCES

From the earliest experiments into practice learning it has been clear that not everyone achieves the same level of skill, even if the same amount of practice has been undertaken. Bryan and Harter (1899), in their investigations of telegraphic operators, note that operators take different amounts of time to learn and achieve different levels of skill, with only a few becoming fully expert. Chapman (1919), in his studies of typewriting notes that individual learning curves show some variation to the averaged curve, although they all conform to a similar pattern.

Differences between groups of people, known as individual differences, have also been noted in implicit learning. Using a colour sequencing task constructed from an artificial grammar which was presented to participants as a memory task, Karpicke and Pisoni (2004), showed that there were significant individual differences in memory for novel sequences for the grammar on which training had taken place, correlated to the auditory digit span. Most, but not all of the participants, showed some implicit learning of the grammar. This indicates that implicit learning is not an inevitable consequence of task presentation. Performance on the Iowa Gambling Task, which requires implicit learning of the yields of the card decks, has been shown to result in two broad groups amongst a non-clinical population – those who could learn and those who could not (Glicksohn, Naor-Ziv, & Leshem, 2007).

Individual differences may be apparent in the learning, application and modification of strategies (Sohn, Doane, & Garrison, 2006), as well as in strategy choice and adaptation to changing circumstances (Schunn & Reder, 2001). This research is particularly interested in individual differences in using strategies in practice learning and so experimental evidence indicating that there are such differences will be considered next.

2.6.1 Individual differences in using strategies

Schneider and Shiffrin (1977) consider individual differences between their four participants in the early experiments, but conclude that these relate to performance, not the strategy used. It seems dubious to draw generalisations about strategy from such a small number, as it could be that these people were by chance similar, perhaps because they all had similar educational experiences and training. They also touch on some performance differences in the categorical learning experiment (Shiffrin & Schneider, 1977), which they attribute to the participants either not noticing the possibility of categorising the stimuli or failing to categorise. They suggest that even if the category became encoded, the ‘node’ corresponding to this does not necessarily become part of an automatic response and that categories *“facilitate, benefit and modify controlled search procedures”* (Shiffrin & Schneider, 1977, p145).

Haider and Frensch (2002) found that not all learners acquire the Information Reduction strategy, even after extensive practice, and that the acquisition occurred at different times during practice. This is also apparent in other reported results from the Information Reduction experiments e.g. Haider, Frensch, & Joram (2005). Taken over all the indications are that perhaps 32-48% of participants could be classified as reducers, with another 40% or so not discovering the strategy within the training period and the rest not being classifiable by the various criteria they use. This might mean that these latter participants use the strategy inconsistently or have an alternative strategy. In experiment 1b (Haider et al., 2005) the majority of those classified as reducers (11 out of 14) were able to report verbally that they ignored the redundant letters as well as retrieving the answer from memory. Haider and Frensch take this conscious report as evidence that the strategy shift is at least partly an intentional decision, but their results also indicate that memory retrieval is known

consciously and this could suggest that any strategy enters conscious awareness. Despite classifying participants as reducers or non-reducers, no examination of individual difference factors which might explain these variations in usage have been reported.

Sohn, Doane & Garrison (2006) tested cognitive abilities and on the basis of general reasoning, spatial visualisation, perceptual speed, spatial problem solving and verbal comprehension divided their participants into high, medium and low ability groups. They were then tested on the polygon shape discrimination task. Sohn et al. found that the high ability group were able to develop a precise strategy which transferred readily to novel stimuli, if trained on the difficult-first shapes, or if trained on the easy-first were able to shift strategies effectively on transfer. Low ability individuals were also little affected by transfer regardless of initial training because they did not develop an accurate strategy in the first place. The medium ability group was differentially affected by transfer – those who had been trained on difficult stimuli had an effective strategy which transferred, those trained with the easy stimuli did not develop an effective strategy to deal with the difficult discrimination on transfer. In other words, cognitive ability affected both which strategy was used and ease of transfer in the polygon discrimination task. This suggests that certain cognitive abilities need to be taken into account when training in situations that could lead to an Information Reduction strategy developing, although Sohn et al. did not separately analyse the correlation of the individual tests they utilised with the accuracy results before and after transfer.

White, Cerella and Hoyer (2007) suggest that even though memory-trace formation, as theorised by Logan, is an inevitable consequence of repeated encounter with the stimulus, it may be that retrieval is a conscious strategy which can be controlled. This could be either by choosing to retrieve or choosing to use the

retrieved solution. White et al. (2007) carried out an experiment where both younger (<26) and older (>60) adults were tested on two types of list, either distinctive or confusable, in an Alphabet Arithmetic task and found that the older adults were less likely to rely on their memories, particularly for the more confusable solutions. It is speculated that this may be due to a lack of confidence in memory for the older participants. For both sets of participants a switch (if it happened) to relying on retrieval occurred later during training for the more confusable items. It was also noted that some participants seemed to use a retrieval strategy consistently for some items but not others.

2.6.2 What psychological factors could be involved in the individual differences seen?

A variety of factors are likely to be involved in the individual differences seen in strategy development. As noted in section 2.6.1 Sohn et al. (2006) found differences in visual discrimination when a number of cognitive abilities were tested, although it is possible that only one or two of the abilities they tested were actually implicated. The factors involved may depend on the precise task, as it is generally held that skill development *per se* is not differentiated by IQ or memory. Considering Information Reduction, and particularly the Alphabet Verification task, it might reasonably be supposed that differences in working memory and attention might account for some or all of the individual differences in strategy development and use. Alternatively, some participants may be aware that they could learn which are the correct and incorrect triplets but do not trust their memory, as was suggested for the older participants in White et al.'s (2007) experiment. Choosing to continue with the counting algorithm may affect application of Information Reduction.

Evidence has been presented that attention can play a part in near transfer of skills (Woltz, Gardner, & Gyll, 2000), which is not dissimilar to the transfer testing utilised in the Alphabet Verification task and other Information Reduction-type tasks. Measures of selective attention such as the Stroop paradigm have been used to demonstrate its involvement (Woltz et al., 2000). It has been reported that there is no evidence for individual differences in the ability to focus or divide attention (Lansman, Poltrock, & Hunt, 1983). Inattentional blindness could be considered a corollary to Information Reduction, where there is a failure to perceive something unexpected (the gorilla) rather than a failure to perceive something expected (the letter string). In one experiment, 42% failed to see the gorilla (Seegmiller, Watson, & Strayer, 2011), which is not very different to the percentage of people reported to be reducers (Haider & Frensch, 1999a). Little work has been done so far in elucidating factors which could contribute to inattentional blindness, but variability in attentional control is suggested as a mechanism (Seegmiller et al., 2011) and this is linked to working memory.

It has been reported that working memory factors, such as its limited capacity, may play a role in improving latency early on in skill acquisition as it is the route by which information gets transferred to long-term memory (Shiffrin & Schneider, 1977). It is likely that memory for the correct triplets plays a part in the Alphabet Verification task, as latency improves even when there are no additional letters beside the triplet (see, for example, the control condition in experiment 1 in Haider and Frensch, 1996), and participants have reported that memory was a strategy they used (Haider & Frensch, 2002). However, this will involve longer-term memory and working memory may not be critical for this. Working memory is implicated in attentional control though and so could play a part via this executive function (Kane & Engel, 2002). Kane and Engel report that working memory span, as measured by

span tasks embedded in other processing tasks, reliably measures its capacity, and that working memory span is also highly correlated to fluid intelligence.

Whilst overall IQ may not play a part, the elements making up ‘intelligence’, particularly fluid intelligence, may exert some influence over the learning of strategies, although the extent to which such factors have a role in implicit learning could be debatable. Fluid intelligence is considered to correspond to non-verbal reasoning and ability to solve novel problems, identifying underlying patterns and relationships. It is often measured using Raven’s Progressive Matrices. Individual differences in personality factors such as conscientiousness have been suggested as a predictor for inattentional blindness (Simons & Jensen, 2009) although this has not been shown to correlate with either fluid intelligence or executive functions (Unsworth et al., 2009). Unsworth et al. found that extraversion was negatively related to vigilance, which is the ability to sustain attention on a task. Other executive functions they examined, such as fluency (the ability to generate unique examples from memory), seem unlikely to be very relevant to the Alphabet Verification task.

2.6.1 Summary

It is apparent that individual differences can affect strategy development in different ways – some may not develop a strategy at all, although conceivably if given explicit instruction would. Of those who develop a strategy, some may do so more quickly than others. There may also be differences in application of the strategy.

Overall, then, it would seem that fruitful avenues to explore in the investigation of individual differences in development and/or use of strategies would be attention either as a single construct or in combination with working memory and fluid intelligence as part of executive function. Some personality factors such as

conscientiousness and extraversion may play a role, and are something that could be investigated reasonably easily.

2.7 CONCLUSION

This review has shown that practice is vital for acquisition and maintenance of skill with the pattern of improvement in speed and accuracy during practice identical in many domains. This suggests that the same underlying processes are in operation despite the fact that the rate of improvement may vary between individuals. Some people may develop additional strategies which improve their performance further. The main theories that endeavour to account for the basic processes occurring in skill acquisition have been outlined. It has been noted that some learning may occur implicitly, and that this may be particularly true for strategies. It is noted that a variety of strategies may develop, depending on the task. However, the review concentrated on the evidence for one of these strategies, known as Information Reduction. One aspect of Information Reduction that has received little attention is that only around half the participants in the Alphabet Verification task seem to adopt it. It is not clear if the reasons for this are characteristics of the task; characteristics of the training conditions, characteristics of the participants or a combination of all three.

The next chapter will describe the construction of the Alphabet Verification task and the new tasks designed for this study, to explore these aspects, as well as considering the types of analysis to be carried out.

Chapter 3 METHODOLOGY

3.1 BACKGROUND

Over the years a variety of qualitative and quantitative methods have been used to investigate the development of skill in both cognitive domains and those where motor skills are also required. These include observation, diary studies, interviews, verbal reports, simulations and computer modelling as well as experiments. For example, the early studies of Bryan and Harter (1899) used regular testing of trainee telegraphy operators combined with observation and introspection; Ericsson et al. (1993) used interviews and diary studies with violin players of various levels to investigate the role of practice and Schneider and Shiffrin (1977; Shiffrin & Schneider, 1977) used experimental techniques in their classic studies of automaticity.

In order to investigate the processes occurring in skill development, cognitive psychologists have developed tasks which can simulate the repeated practice required, but can be carried out in either one or a few sessions. Using laboratory-based tasks enables standardisation of both task and instruction, and variables to be systematically manipulated, yielding data important for theory development. Despite the artificial nature of many laboratory-based tasks, it is considered that they provide a way for a high level of skill to be achieved in a relatively short interval of time (Proctor & Vu, 2006), an important practical consideration. They are a useful model for practice learning and have yielded valuable insights, showing, for instance, that learning can often be incidental or implicit, and that becoming skilled involves developing higher-level strategies and goal structures as well as automatization of perceptual, cognitive and motor components of a task.

Previous studies into Information Reduction have used the experimental method (Edmunds, 2005; Gaschler & Frensch, 2007; Gaschler & Frensch, 2009; Gaschler et al., 2015; Green & Wright, 2003; Haider & Frensch, 1996; Haider & Frensch, 1999a; Haider & Frensch, 1999b; Haider & Frensch, 2002; Haider et al., 2005), with participants responding to repeated presentation of stimuli in one session. Eye-tracking has also been employed to determine whether participants really do attend less to the irrelevant part of the strings (Gaschler et al., 2015; Haider & Frensch, 1999a), as well as self-report to elucidate what participants have become aware of during the task (Edmunds, 2005; Gaschler et al., 2015; Haider et al., 2005). There has also been some investigation of individual differences – anxiety and IQ - using standardised psychometric instruments (Edmunds, 2005).

This chapter will detail the main task and measures employed in previous Information Reduction studies and then outline the three methods used in this study to address the research questions. These were experimental, self-report and individual difference questionnaires. The chapter will conclude with a discussion of the validity of the data collection procedure.

To start with, in section 3.2 the structure of the Alphabet Verification task that has been used by researchers in many studies (Gaschler & Frensch, 2007; Gaschler & Frensch, 2009; Green & Wright, 2003; Haider & Frensch, 1996; Haider & Frensch, 1999a; Haider & Frensch, 1999b; Haider & Frensch, 2002; Haider et al., 2005) is described. Section 3.2 also describes the analyses applied to the data arising from the Alphabet Verification task. As one of the questions to be considered is whether Information Reduction can be detected in other analogous tasks, section 3.3 describes the development of the tasks to be used in Experiment 1. Other aspects of the research questions will be addressed by the use of post-testing questionnaires.

3.2 THE ALPHABET VERIFICATION TASK

Having noted from the expert-novice literature that a strategy of distinguishing between relevant and redundant information seems to occur, Haider and Frensch (1996) were interested in testing in a cognitive experimental setting whether this is part of skill acquisition. Therefore they needed a task where part of the stimuli was relevant to the response required and part of it was redundant. Another consideration was to be able to track the development of the strategy over the course of practice.

An existing task, the Alphabet Arithmetic Task (AAT) (Logan, 1988), could fulfil the second part of this requirement. In the AAT participants are asked to verify strings of the type

$$A + 2 = C$$

$$B + 3 = F$$

$$C + 4 = G$$

$$D + 5 = J$$

The addend can vary from 2 to 5 and the answer can either be true or false. Initially response times (RT) vary systematically with size of addend but with practice the RTs converge to be equivalent for all. However, this task consists of strings where all the information is relevant to verification and thus was unsuitable for testing Haider and Frensch's hypothesis. Therefore they adapted this task, by replacing the addend with a bracketed digit between two letters (e.g. D(4)I or D(4)J, henceforth known as the 'triplet') and including a variable number of additional letters after the triplet, none of which were relevant to verifying the letter string. However, the instructions at the start of the experiment were that errors could occur anywhere in the string, thus participants were encouraged to check the whole string. It was expected that

initially RTs would vary systematically with the number of additional letters. The task is known as the Alphabet Verification task and the variation in RTs seen with the increasing number of additional letters is the ‘string-length effect’.

The digit represented the number of letters to be skipped: thus D(4)I is correct because the four letters E, F, G and H are skipped but D(4)J is incorrect since there are five letters between D and J. Haider and Frensch do not explain how the parameters of the task came to be chosen, for instance, why the digit 4. Also they did not use letters from the very start or end of the alphabet, possibly to avoid the extremely over-learned sequences of ‘A, B, C’ and ‘X, Y, Z’.

Strings started with different letters and between zero and four consecutive ‘trailing’ letters were appended to the triplet, to give five correct examples for each starting letter. There would be another five incorrect examples for each starting letter, which always had five letters missing in the triplet, although the digit remained as 4. This gave strings of the type:

D(4)I J	correct string
D(4)J K L M	incorrect string
K(4)P Q R	correct string
K(4)Q	incorrect string

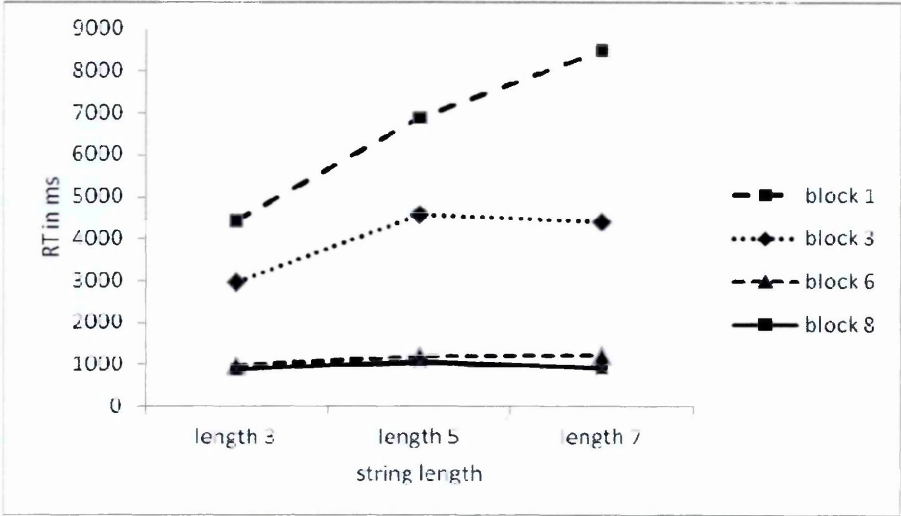
During the training blocks the trailing letters were always consecutive and correct, so that verification of whether the string was correct or incorrect could be achieved by processing only the triplet portion of the string. However participants were not generally informed of this regularity. Typically an experiment involved 80-100 of these ‘regular’ strings per training block, with half being correct and half incorrect. Each training block would be repeated a number of times, so that over the course of training each individual string would be seen several times, thus additionally

providing a test of the Instance Theory (Logan, 1988, see also section 2.2.3 in Chapter 2). Haider and Frensch suggest that using 10 starting letters, with zero to four additional letters, results in 50 unique instances of correct strings and similarly 50 unique instances of incorrect strings. However, it could be argued that, if, for instance, the procedure for verifying the strings consisted of two main components: “count through the letters where the digit is” and “check the other letters against the alphabet”, the triplet and the other letters might be processed as two separate sets of instances, and this would mean that in fact there were only ten unique correct instances and ten unique incorrect instances of the triplet. Given the limited number of letters in the alphabet and the need to have a variable number of additional letters this repetition is unavoidable, but it does have the potential to confound instance learning with Information Reduction. However, assuming that instance learning will apply equally to all stimuli, since they are all seen the same number of times, means that examination of the change in the ‘string-length effect’ over training gives an indirect measure of Information Reduction.

To examine the string-length effect, a linear regression on the mean RTs for the various string lengths, by block and by participant, was carried out. The regression essentially plots a straight line through the data points for the RTs and calculates a coefficient for the slope. The regression slopes at the start of the experiment suggested that the string-length effect was evident – that is the slopes were positive. An ANOVA on the regression slopes over the blocks demonstrated that the RTs to the longer strings decreased reliably more than those to just triplets over the course of practice, indicating that the verification time for longer strings had reduced to near equivalence with the shorter strings. Figure 3.1 illustrates RTs for one participant throughout Experiment 1, reported in Chapter 4 of this thesis, showing how the RTs decline and the slope changes. Haider and Frensch concluded

from their results that participants had learned that they needed to check only the initial letter-digit-letter triplet and could ignore any trailing letters, showing Information Reduction. Therefore this seemed a suitable methodological tool with which to investigate this strategy.

Figure 3.1: RTs by string length and block for one participant in Experiment 1, reported in Chapter 4 of this thesis, multiple-triplet task



There is also an additional way of testing if the trailing letters are really being ignored, and that is to start having alphabetic irregularities in the latter part of the string, with a correct triplet. This is known as an ‘irregular’ string. If participants have learned not to process the trailing letters then they will not notice errors occurring there. Haider and Frensch (for example, Experiment 2, 1996; Experiment 1, 1999a) added a test block with a proportion of irregular strings. These alphabetic inaccuracies were achieved by omitting a letter from the sequence, for example:

D(4)I J L M
 K(4)P R

Many participants responded that these irregular strings were correct, indicating they were only processing the (correct) triplet and ignoring the (incorrect) trailing letters. Consequently there was a high rate of errors to these strings, with the number of errors increasing if more practice blocks had been experienced. Information

Reduction is deemed to have occurred where both a reduction in the string-length effect over practice is observed and responses in the test block show either a high rate of errors to irregular strings, or a return of the string-length effect.

In one study (Haider & Frensch, 1999a) the reduction in string length effect, as measured by the regression slopes, was correlated against the number of non-triplet errors in the test block and this found a significant correlation, suggesting that they may both be measuring the same effect.

3.3 METHODS USED IN THIS STUDY

The main methodology adopted for this series of studies was the experimental paradigm of Haider and Frensch, with post-testing questionnaires also being used. Presentation of stimuli and recording of RT to each stimulus, along with incorrect responses, was achieved via a computer program. The post-testing questionnaires used consisted of a short series of questions related to the task carried out (Appendix 1) and, for experiments 4 and 5 reported in chapters 7 and 9, some previously validated individual difference instruments which were freely available from published papers, internet sources or individual researchers (Appendices 2-6).

3.3.1 Design of new tasks

One aim was to determine whether Information Reduction would be seen in tasks analogous to the Alphabet Verification task, or whether it is an artefact of this task. In order to explore this it was necessary to develop some alternative tasks. To facilitate comparisons between these new tasks and published results on the Alphabet Verification task, the new tasks were designed to have the same parameters:

- one element that was relevant to fulfilling the task and at least one other element that was irrelevant

- a variable number of irrelevant elements so that the equivalent of the string length effect could be detected
- a method of introducing relevance into the formerly redundant element(s) to test for increased errors/return of the 'string length effect'

The Alphabet Verification task can be criticised for the fact that each stimulus breaks down into two perceptual units: the initial letter-digit-letter triplet and the trailing letters, which Haider and Frensch have observed to have different perceptual saliency and complexity. This may lead to differential processing, for instance, the trailing letters may be processed as a pre-existing instance, since they are well-learned sequences. Consequently some participants may not process each letter individually and thus not show a string-length effect. Therefore another consideration for the new tasks was to avoid continuous strings of letters from the learned forward alphabet sequence, to encourage the participants to process element by element initially.

A marginal note in Haider and Frensch (1999a) referring to Lincourt, Rybash, & Hoyer (1998) suggests that Information Reduction had also been detected in a task where the whole stimulus consisted of letter-digit-letter triplets. A task requiring more calculation could lend itself to greater use of a strategy like Information Reduction and with further triplets to compute the string-length effect should be apparent for all participants. It will be seen that in order to create different sets of stimuli the digit used did not remain as 4 in the various experiments. This task is henceforth known as the multiple-triplet task.

One completely novel picture-matching task was devised (see Chapter 4). Participants were required to make a same/different judgement between two adjacent boxes containing between 3 and 6 geometric shapes, with the differing

shape always located in the same place in training. The locations of the other shapes within the box varied from trial to trial, although the blocks were repetitions of each other. In the test block the differing shape was randomly positioned elsewhere. It was anticipated that boxes with more shapes would take longer to process than those with fewer, mimicking the string-length effect. This task differs from the others in that there is no clear place to start checking, unlike the linear letter strings, and consequently a string length effect may be apparent for both matching and differing stimuli. This task will be referred to as the shapes task.

The target search task was developed by Edmunds (2005) and involves presenting a memory set of three letters followed by blocks of random letter strings of 3-7 items. In training the strings either contain one item from the memory set at position two, or do not contain a memory set item. For target-absent trials the whole stimulus should be processed element-by-element initially, creating a string-length effect. In the test block the position of the memory set item is anywhere from item three onwards in the 'irregular' trials. The task also addresses one of the criticisms of the Alphabet Verification task by avoiding pre-existing perceptual segmentation.

Examples of the stimuli can be seen in Table 4.1 in Chapter 4, and Tables 9.1 and 9.4 in Chapter 9.

3.3.2 Experimental method

The method employed was as close to the experiments of Haider and Frensch as possible, in order to be able to make comparisons between the tasks and conditions. The multiple-triplet task uses the alphabetic sequence and is subject to the same criticisms as the Alphabet Verification task, in terms of repetition of the stimuli; the other two tasks lent themselves to supplying a wide range of unique

instances, but these were restricted to similar repeating constraints as in the Alphabet Verification task so as to enable comparisons between the tasks.

Although Haider and Frensch give the approximate size of the letters in their display, they do not specify which font was used, nor letter colour or background colour. In the papers by Gaschler and Frensch, the font is given as Courier New (which has each letter the same size and spaces them equally), black on a pale yellow background, although the RGB dimensions for the background are not given. For stimuli containing letters, in the experiments reported here, Courier New font was used, with the letters approximately the same dimensions on screen as Haider and Frensch report, in order to keep as closely as possible to their presentation. However, pale yellow was not available as a background with the programs used so it was kept as white.

Participants were given instruction as to how the stimuli were constructed and which key to press for which response. They were told to attend to the whole stimulus and to work as quickly and accurately as possible, except where speed was being manipulated. There was a practice block of 10 trials, with feedback. Incorrect responses to more than 3 trials resulted in the practice repeating, which should ensure that the requirements were understood. In all experiments, except the feedback manipulation experiment (Experiment 2, Chapter 5) trial-by-trial feedback was given throughout the training trials. Anyone who had over 10% errors during training was excluded from the analysis on the basis that they either did not really understand the task or did not carry it out correctly. The figure of 10% is in line with previous experiments (Haider & Frensch, 1996; Haider & Frensch, 1999a). Stimuli were randomly presented within each block.

As well as the training blocks there was a test block in which the location of errors was moved in 20% of the incorrect stimuli. Haider and Frensch (1996; 1999a)

demonstrated that giving feedback during the test block meant that participants were more likely to become aware that errors were appearing in the previously irrelevant part of the stimulus. Therefore, although initially the error rate rises, it soon drops again but conversely the string length effect returns, as participants revert to checking the whole string. Piloting for Experiment 1, reported in Chapter 4 of this thesis, suggested it was preferable not to give feedback as the change in relevance was spotted after just one or two incorrect responses. Without feedback those who have adopted the Information Reduction strategy ('reducers') should continue with their reduced processing, although they may still become aware of the change. This could be because the lack of feedback on that one block acted as an alert that conditions had changed. Not giving feedback in the test block gives the opportunity to test the correlation between the reduction in string length effect against irregular errors, which has previously only been done in one experiment (Haider & Frensch, 1999a). This also potentially provided a way to distinguish those who were 'reducers' from those who were 'non-reducers', which was another aim of the study.

3.3.3 Analyses

Analyses were identical to those generally employed. Firstly comparing error rates between the final training block and the test block, distinguishing between errors made to regular and irregular stimuli. Secondly, ANOVA of mean RTs per block. Thirdly, computing the regression slopes for each participant and each block, using stimulus length as the predictor and RT as the dependent variable and then carrying out an ANOVA to test for any change over the course of the experiment. It was expected that error rates to 'regular' stimuli (the correct and incorrect stimuli seen in training) would be similar between the final training block and the test block, but that reducers would show a significantly larger error rate to the 'irregular' stimuli. Analysis of the error rates and the change in regression slopes show if Information

Reduction was being used at an aggregated level, and could also be used to examine what individuals were doing. In two experiments Haider and Frensch (2002, 2005) used a drop in RT of over a second between blocks as an indication of Information Reduction, but this could just indicate that any strategy has started to be used and therefore may not be a specific test for Information Reduction. Also this would not detect anyone who starts using Information Reduction in the first block.

One problem that is apparent is how to distinguish the effects of using one strategy from another, since participants may employ more than one at a time. Analysis of the 'string length effect' by computing regression slopes does remove the factor of speeding due to triplet memory, since it is essentially a way to subtract this portion of the RT. Edmunds (2005) pointed out that the difference between the slopes for correct and incorrect strings could indicate the extent of Information Reduction, if it is assumed that processing of incorrect strings terminates once the triplet error has been noted. If use of the strategy is conscious knowledge then one possible way that the strategy used can be determined is by the use of post-testing questionnaires.

Edmunds (2005) examined whether it was better to consider standardised β coefficients rather than b in the regression and concluded that they give similar results and both are sensitive to a reduction in the string-length effect, confirming that it is not simply an artefact of the analysis. He also considered whether the effect noted and labelled as Information Reduction could in fact be due to fatigue. He carried out a small experiment to test for this, in which every block contained a significant proportion of irregular strings, forcing participants to continue checking the whole string throughout. Since no Information Reduction was seen under those conditions, the conclusion was that the results attributed to Information Reduction were unlikely to be explained by a fatigue effect.

3.3.4 Post-testing questionnaires

Haider and Frensch have hypothesised that Information Reduction is consciously applied and therefore it is anticipated that there should be awareness of the relevance of parts of the stimulus and the redundancy of other parts. Short questionnaires to determine what conscious knowledge of the task participants had on completion have been used in a number of studies (Edmunds 2005; Gaschler et al., 2015; Haider & Frensch, 2002; Haider et al., 2005). The questions used here were adapted from those used by Edmunds. They were general to start with and then became more specific, to probe how much participants were able to verbalise about the task. An example list of the questions is in Appendix 1. They were analysed by categorising the responses, for instance, whether information about only processing the relevant information was freely volunteered and whether the participant indicated that they had used the regularity when carrying out the task, and then counting the total numbers in each category. In addition the responses were related to the individual's regression slopes and error rate as part of classifying whether they were 'reducers' or 'non-reducers'.

There are limits to what can be deduced from such questionnaires, since wording of any question is open to interpretation and may not be understood in the manner intended, thus some may not report their knowledge about the task. Also the point at which any strategy started to be used cannot be accurately determined, as it relies on a post-hoc estimation by the participant. The answers were only used to generate basic categorical data, as that was all that was required to map onto the RT and error data, and were not analysed in a qualitative way.

The following instruments were used as tests of individual differences, in order to establish whether reducers could be distinguished from non-reducers by one or more of these means: the functional/dysfunctional impulsivity scale (Dickman,

1990); the Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald, & Parkes, 1982), a measure of distractibility (Forster & Lavie, 2007); the Squire Subjective Memory Questionnaire (Squire, Wetzel, & Slater, 1979), a measure of trust in memory; the Cognitive Reflection Test (Frederick, 2005, and personal communication, 2014) and the personality factors of agreeableness, conscientiousness, extraversion, neuroticism and openness to experience. Questions to tap the latter were taken from the International Personality Item Pool (<http://ipip.ori.org/>). These can be found in Appendices 2-6 and will be discussed in more detail in Chapter 8 on individual differences.

3.4 DATA COLLECTION

The method of data collection mainly utilised in these experiments was to send a program file over the internet to the participant for them to carry out the experiment using their own computer and then return the datafile. Whilst still somewhat unusual for RT experiments such as those reported here, this approach to data collection is becoming more common (Keller, Gunasekharan, Mayo, & Corley, 2009). Internet-based data collection started in 1994 and is now widely accepted (Reips, 2002). Nonetheless, concerns may be raised as to whether experiments carried out without the normal laboratory level of control are valid and reliable (Corley & Scheepers, 2002). Potential issues arise around whether the participant understands the instructions, remains on task, is interrupted and over the variety of hardware in use (Crump, McDonnell, & Gureckis, 2013), all of which could affect the data collected. However, advantages of web experiments include a reduction in experimenter and demand effects (Crump et al., 2013; Reips, 2002). Crump et al. also point out that there is more natural variation in participants' RTs than in the timing differences between different computer systems.

Studies have demonstrated that data collection carried out in the participants' own environment and not under a researcher's supervision is as valid and reliable as in the laboratory, despite the variety of hardware in use. Corley and Scheepers (2002), using a timed linguistic priming experiment via a web-based package (WebExp), were able to show the same priming effects as had previously been obtained in a laboratory study. The WebExp package is implemented as a Java applet in the participant's browser and interrogates the operating system in order to capture timing data (Keller et al., 2009). Keller et al., as well as demonstrating that WebExp was able to show the same effects and generate reading times matching those of a previously published study investigating reanalysis in sentence processing, also showed that it could measure the duration of a known time interval reliably. Crump et al. (2013) replicated several 'classic' RT experiments (Stroop, task-switching, flanker, Simon, and Posner cuing), using an HTML webpage and running JavaScript locally in the browser, recruiting participants through Amazon.com Mechanical Turk. They found comparable results to those obtained in the laboratory and conclude that even small RT effects of ~20ms can be reliably measured this way. The results also suggest that participants completing the experiment and returning data do remain on task throughout. Keller et al. (2009) acknowledge that network latency could be a problem for web-based RT studies, but this would not be a problem for studies such as that reported here, which are carried out entirely on the participant's computer, not through a browser, with the internet only used for file exchange.

Participants were recruited from an Open University Psychology module or from the Open University Virtual Participant Panel by email invitation (Reips, 2002; Reips, 2012), which ensured that no-one participated more than once. Participants received no form of compensation for their time. Crump et al. (2013) found that

incentive simply altered the rate of recruitment, not the quality of the data. All participants were given 10 practice trials, which repeated if more than 3 incorrect responses were recorded. This helped to ensure that the participants understood the instructions. Crump et al. conclude that instructional checks are required in learning experiments. Additionally, those who had over 10% errors throughout the experiment, which indicates the task was not carried out correctly, perhaps due to misunderstanding the instructions, were not included in the analysis. Inspection of the data on receipt of the file suggested that in a very small number of trials (0.04% across all participants, tasks and experiments) an individual RT was excessively long, possibly due to an interruption of some sort, and these data points were removed. A statistical comparison of data collected for Experiment 1 under laboratory conditions with that collected from participants via the internet shows no significant differences between RTs and the regression coefficients for the slopes at the beginning or end of the training (Appendix 7).

After returning the datafile, participants were emailed either the post-testing questionnaire as a word-processed document to complete and return (Experiments 1-3), or a link to a survey set up in Qualtrics containing both the questions about the task and some individual difference questionnaires (Experiments 4-5). Using a web-based survey gives an ability to maintain consistency of factors such as page layout and order of presentation of questions (Hewson, 2014), although it was not necessary to use some of the other features available in the package.

3.4.1 Reflection on data collection

Although I had access to a number of cohorts of Open University psychology students and to the Virtual Participant Panel, actually collecting the data proved to be a long drawn-out process. Of all those invited to participate, only a small fraction (around 10-15%) volunteered and then there was further attrition between

responding to the invitation and returning data. In many cases the reason for this was not communicated to me but some participants reported problems running the software and it is likely that some of the other failures to return data had the same cause. Additionally, given the repetitive nature of the task and the time requirement, other participants may simply have withdrawn part-way through, either through boredom or being interrupted or needing to attend to some other task. Whilst participants are always told of their right to withdraw, it may be easier to do this if not 'under the eye' of the researcher. By the very nature of internet-based research, it is hard to find figures comparing the level of withdrawal with that experienced in laboratory-based research. However, it is known that an absent experimenter will reduce the level of obedience (Meeus & Raaijmakers, 1986). Those who volunteered to participate were inevitably a self-selecting sample, although being Open University students were more diverse, certainly in terms of age, than is typically found in many other experiments.

Some issues were encountered with the emailed link to the Qualtrics survey, which in some cases appeared to be blocked by the participant's email provider. This was discovered in some cases where a participant contacted me to say they had not received it. The difficulty was overcome if they had an alternate email address. In other cases it was not possible to know if the link had not been received or if the participant chose not to complete the questions. Overall 44 questionnaires were not returned, from 394 participants who contributed analysable data. This gave a response rate of 89%, which is likely to be higher than that normally experienced for internet-based questionnaires, and probably reflects the fact that most of the attrition had already occurred at the recruitment stage.

Chapter 4 EXPERIMENT 1

EXPERIMENT TESTING NEW TASKS¹

4.1 INTRODUCTION

Previous experiments in the literature manipulating the Alphabet Verification task have enabled a number of conclusions to be drawn about the process of Information Reduction, whereby there is an additional speeding over the course of practice which cannot be explained by theories of automaticity, such as the Instance theory (Logan, 1988) or the Production rules theory (Anderson, 1987). It has been hypothesised that Information Reduction occurs in two stages, with implicit learning of a regularity being bottom-up and data-driven and leading to a top-down strategic switch to ignore, at a perceptual level, irrelevant elements of a stimulus (Haider & Frensch, 1999b). Whilst it has been noted in other fields that just relevant information is used (e.g. Doane et al., 1999; Lee & Anderson, 2001), only Haider and Frensch have attributed this to a non-automatic mechanism. Therefore it would seem prudent to demonstrate Information Reduction in other tasks than just the Alphabet Verification task, to ensure that the results seen are not simply an artefact of this task. For instance, it could be that the construction of the stimuli themselves affords processing which appears to be Information Reduction. Stimuli in the Alphabet Verification task consist of two sections which differ in perceptual salience and in complexity, thus potentially preferentially attracting attention to one, which happens to be the relevant section, above the other. Additionally, the second section consists of alphabetically ordered letters that participants will have encountered

¹ The experiment reported in this chapter was included in the paper: Information Reduction—More than meets the eye? (2015), Nancy E. Rowell, Alison J. K. Green, Helen Kaye & Peter Naish, *Journal of Cognitive Psychology*, 27:1, 89-113, DOI:10.1080/20445911.2014.985300

many times, thus possibly needing minimal processing or even already existing as instances which can be retrieved in one step, as theorised by Logan (1988).

There are aspects of the results obtained by Haider and Frensch, such as the observation that some do not use the strategy, that do not appear to have been examined. In the triplet-position-varying experiment, Haider and Frensch (1999a) suggest that roughly 40-50% of participants can be classified as 'reducers'. Later experiments (Haider & Frensch, 2002; Haider et al., 2005) also give similar figures. What cannot be determined from these papers is whether non-reducers have noticed the regularity of errors in training but chosen to ignore this information or whether the regularity has not been detected and therefore cannot be used. If Information Reduction is a general learning mechanism, available to all, then further exploration of the reducer/non-reducer divide is needed. Using the test block error rates and reductions in the string length effect it may be possible to identify reducers from non-reducers. If rates of reduction remain the same with a variety of tasks and alterations to training conditions then it could be concluded that people are dependably one or other. Post-testing questionnaires may reveal the levels of awareness of the regularity amongst non-reducers. The results would provide evidence that could be used in theorising about the processes involved.

Haider and Frensch also believe that Information Reduction is a strategy that is consciously applied as a result of learning and each person uses it consistently on all stimuli of the same type from the point of adoption onwards. However, it has been shown that a strategy change from algorithmic processing to memory retrieval can be gradual, rather than abrupt (Rickard, 1997). Experimental evidence is divided as to whether strategy shifts are conscious decisions or not: Doane et al. (1996, 1999) believe that the Information Reduction-like strategy seen in their polygon-matching task was subconscious. Touron and Hertzog (2004a, 2004b) probed participants

during the noun-pair look-up task to determine whether they were using a memory strategy or continuing to scan the table. Their results indicated that participants were aware and able to report which method they were using. Testing a form of Information Reduction aligned with implicit sequence learning (Haider, Eichler, & Lange, 2011), using both inclusion and exclusion tasks, suggested that knowledge of a regularity/strategy entered conscious awareness for only 34-41% of participants and that some participants used the strategy without conscious awareness of it. Since conscious processes are generally controlled, they would also be effortful and slow (Moors & De Houwer, 2006), requiring attention and subject to the vagaries of this resource, which would preclude absolute consistency in usage. On the other hand, Information Reduction appears to incorporate elements of automatic processing, in that it is fast and could be considered effortless since usage makes processing more efficient and thus may not be as consciously applied as Haider and Frensch have suggested. Conscious knowledge can be assessed by questioning participants about their awareness (Haider et al., 2011). If Information Reduction is a consciously available strategy then it should be reportable in some sense. R nger and Frensch (2010) argue that verbal report is the most sensitive and valid measure of conscious awareness of an implicitly learned sequence.

The multiple-triplet task was developed from the Alphabet Verification task, but the entire string consists of letter-digit-letter triplets, to address the criticism that in the Alphabet Verification task, the relevant part is more salient and complex than the irrelevant part. Due to the limited number of letters in the alphabet, and the fact that computing two or three ‘gaps’ of four letters would be time consuming for the participants, it was decided to keep the initial digit as 4 to match the complexity of the Alphabet Verification task, with subsequent digits being 2. The regularity was that alphabetic violations always occurred in the initial triplet in training, but

elsewhere in the string in the test block. Half the trials were correct and half incorrect. The second task used was the shapes task and required participants to make a same/different judgement between two adjacent boxes containing between 3 and 6 geometric shapes. The regularity was an alteration to the orientation of the shape placed middle right, with irregular stimuli having an orientation change to a shape elsewhere in the box. Half the trials had matching boxes and half contained one differing shape. The third task employed in this experiment was the target search task (Edmunds, 2005). Participants were required to search a variable length letter string for a letter in the memory set of C, O and V. Half the trials were target present, and half were target absent. In target present trials in training the target was always located at position 2 in the string, reading from the left, and anywhere from item 3 onwards in irregular strings in the test block. The non-memory set letters in each string were randomly generated with no intentional alphabetic sequence or word included. Although it can be used with completely new instances on every trial, for the purposes of this study training strings were restricted so that the initial three letters repeated within blocks with varying numbers of subsequent letters, and the same set of stimuli were repeated in each training block. Examples of the stimuli can be seen in Table 4.1.

This experiment served two purposes: first to test if Information Reduction is used in tasks analogous to the Alphabet Verification task, and second to indicate, if possible, the numbers using it in each task. The results of the experiment form a control for other experiments which use an identical procedure apart from one specific manipulation of training conditions or stimuli. Chapter 3 has outlined the three tasks used: the multiple-triplet task, the shapes task and the target search task. The hypothesis was that Information Reduction, as detected by a reduction in regression slopes over training and either a large number of errors to "irregular"

stimuli in the test block or a re-emergence of the string-length effect, would be seen in the new tasks.

4.2 METHOD

4.2.1 Participants

There was a total of 71 participants, 45 students of the Open University who had recently completed a psychology module and 26 members of the Open University Virtual Participants Panel, who were mainly staff and psychology students of the Open University. 15 were male and 56 were female. There were 25 (4 male) in the multiple-triplet task, 23 (4 male) in the target search task and 23 (7 male) in the shapes task. Their ages ranged from 24-61², mean age 39. All participants performed one task only.

4.2.2 Materials

To construct the multiple triplets 10 initial letters were used (B to K inclusively). Each initial letter was used once each with single, double and triple triplets, resulting in 30 correct strings. To construct the 30 regular incorrect strings the second letter, immediately following the digit 4, was substituted with the next one in the alphabet and this meant that any following letters were also shifted one, e.g. B(4)G(2)J became B(4)H(2)K. For the test block 12 irregular strings were constructed by keeping the initial triplet as the correct strings, but changing the third or fourth letter to the next in sequence e.g. B(4)G(2)K. For the practice trials, five correct, three incorrect and two irregular strings were selected.

For the shapes task, the following were selected from those available in Powerpoint: four-pointed star, isosceles triangle, right-angled triangle, diamond, hexagon, block

² No age effects were detected – see Appendix 8 for an analysis

arrow, trapezium, block cross, arch, cube and rectangle. Each of these served as the 'target', with the rectangle being used as the target in the practice trials. A Python program was used to randomly generate sequences of two, three, four and five shapes from this selection, with duplicates being allowed. There were 20 sequences at each length, giving 80 shape sequences overall. Within a larger rectangle (box) the target shape was positioned in the right middle and the other shapes were randomly placed around the rectangle. This was then duplicated so that the two boxes containing the shapes appeared side by side on the slide. For half of the 80 slides created in this way, the target shape was rotated in the right hand box, giving 40 correct (matching) and 40 incorrect (differing). To create the 'irregular' trials in the test block, the position of the target shape was swapped with one of the other shapes for 16 of the differing slides.

To construct the strings for the target search task a Python program was used to generate 20 random three-letter strings, from almost the entire alphabet, but excluding C, O and V, to serve as the within-block-repeating part of the string. Duplicate letters were allowed. For 10 of these the second letter was substituted with one of the target letters C, O or V, used in rotation, to create the target present strings. This gave 10 target present and 10 target absent strings. Each of these then had zero, one, two, three and four additional letters, also generated randomly from the Python program, added, so that each initial triplet was used five times, giving 50 target present and 50 target absent strings. Again, duplicate letters (excluding C, O and V) across the whole string were allowed. For the test block, in 20 of the target present strings the target letter was swapped with the letter in one of position three, four, five, six or seven to create the irregular strings. This was done with equal numbers of each length. For the practice trials, 5 target present, 3 target absent and 2

Table 4.1: Examples of the different types of stimuli for each task

Task	'Regular correct' stimulus (whole stimulus should be processed initially)	'Regular incorrect' stimulus (processing should cease when error/target/difference found)	Irregular stimulus (used only in test block)
Multiple-triplet	<i>String follows alphabet</i>	<i>Incorrect letter immediately after first digit</i>	<i>Incorrect letter after second or third digit</i>
	I(4)N	I(4)O	I(4)N(2)R
	I(4)N(2)Q	I(4)O(2)R	I(4)N(2)Q(2)U
Shapes	I(4)N(2)Q(2)T	I(4)O(2)R(2)U	
	Boxes match	Boxes differ - shape middle right in right-hand box rotated	Rotated shape elsewhere in right-hand box
Target search	Target absent	Target present at second position	Target present later in string
	A H G	E V F	M F V T
	L K N H B	H O G Y	A H E Z C
	U A B K D J	F C T L H S P	N N A X O I B

irregular strings were generated on the same principles, but with different initial triplets.

4.2.3 Procedure

Most participants were tested remotely by downloading the experiment file to their computers, although eight participants in the shapes task were tested under laboratory conditions, all on the same computer. Remotely tested participants were asked to carry out the task in a quiet room with no interruptions. The briefing and task were presented via the computer program – either using the experiment generator package E-Prime 1.2 (Psychology Software Tools, Pittsburgh, PA) or the open source software Python. This ensured standardisation of the procedure, which included reminding participants of their right to withdraw, confidentiality and anonymity of data, as well as providing contact details of the researcher.

After briefing, the participants were presented with detailed instructions about the task, given examples of all three types of stimulus and the response required. Participants were instructed to be as fast and accurate as possible. The experiment started with a practice session with 10 trials, with immediate visual feedback on whether the response was correct or incorrect. If more than three responses were incorrect then the practice repeated. Each trial consisted of a fixation cross displayed in the centre of the monitor for one second, followed by the stimulus which stayed on screen until a response was made, and then the feedback of ‘correct’ or ‘incorrect’ was displayed for 500ms.

The training trials, which took place in blocks after the practice, were the same except that a blank screen was displayed for 500ms when the response was correct and visual feedback was only given if there had been an incorrect response. At the end of each block the participants were encouraged to take a short break.

The test block, containing the ‘irregular’ stimuli, followed the training blocks with no indication that it was in any way different. In this block no feedback was given at all, as piloting had suggested that participants became aware of the change in stimuli very quickly if informed of incorrect responses. Instead every trial was followed by a blank screen for 500ms.

At the end of the experiment, participants were thanked for their participation and reminded to return the results file to the experimenter. On receipt of a datafile, the participants were requested to complete a few questions about the task (Appendix 1), supplied in a Word document, and once this had been returned were debriefed.

4.2.4 Design

The within-participants independent variables were block, ‘string length’ and type of ‘string’: regular correct, regular incorrect or irregular, as indicated in Table 4.1. For the multiple-triplet task the string length was one, two or three triplets, for the shapes task it was 3-6 shapes and for the target search task it was 3-7 letters.

There were 60 strings per block in the multiple-triplet task, with 8 training blocks, giving 480 trials during training. There were 80 shape stimuli per block in the shape matching task, with 6 training blocks, giving 480 training trials. There were 100 strings per block in the target search task, with 5 training blocks, giving 500 training stimuli. In each task half the training strings in each block were correct and half were incorrect. Each task had one practice block of 10 stimuli at the beginning and one test block after the training blocks. The test block had some regular incorrect stimuli replaced with irregular ones – 12 for the multiple-triplet task, 16 for the shapes task and 20 for the target search task.

The dependent variables were response time (RT) to each stimulus and number of stimuli incorrectly responded to.

4.3 RESULTS

4.3.1 Accuracy

The analysis excluded participants with errors in training of 10% or greater for all trial blocks. In the multiple-triplet task three were excluded, leaving 22 participants' data, and in the shapes task one participant was excluded, leaving 22 participants' data. All 23 participants' data from the target search task were analysed.

Table 4.2 shows that similar numbers of errors were made to the 'regular' strings and shapes in the final training block and the test block but more errors were made to the irregular strings, inconsistently placed shapes or inconsistently placed targets. A one-way repeated measures ANOVA (String Type: regular correct, regular incorrect and irregular) on error rates for the test block showed a significant difference among the trial types for each task. For the multiple-triplet task string types, $F(2,42) = 76.64$, $MSE = 62817$, $p < 0.001$, $\eta_p^2 = 0.785$, with the difference lying between the regular and irregular strings (pairwise comparison: regular correct vs regular incorrect $p = 0.269$, regular correct vs irregular $p < 0.001$, regular incorrect vs irregular $p < 0.001$). For the shapes task different shape types, $F(2,42) = 19.18$, $MSE = 3047$, $p < 0.001$, $\eta_p^2 = 0.477$ with each significantly different from the others (pairwise comparison: regular correct vs regular incorrect $p = 0.002$, regular correct vs irregular $p < 0.001$, regular incorrect vs irregular $p < 0.001$). For the target search task string types, $F(2,44) = 58.88$, $MSE = 2635$, $p < 0.001$, $\eta_p^2 = 0.728$ with the difference lying between the regular and irregular strings (pairwise comparison: regular correct vs regular incorrect $p = 0.06$, regular correct vs irregular $p < 0.001$,

regular incorrect vs irregular $p < 0.001$). The effect sizes are large³ for all tasks, suggesting that much of the variance in the error rates is explained by the difference in the stimuli types and that the effect would generalise to the population.

Table 4.2: Overall error rates in final training block and test block by stimulus type

Task	‘String type’	Final training block	Test block
Multiple-triplet	Correct strings	5%	4%
	Incorrect strings	4%	6%
	Irregular strings	-	72.7%
Shapes	Matching shapes	1%	0.8%
	Differing shapes, consistent position	2.8%	7%
	Differing shapes, inconsistent position	-	18.5%
Target search	Target absent	0.1%	0.2%
	Target present, consistent position	0.9%	1.6%
	Target present, inconsistent position	-	15%

In the multiple-triplet task 14 of the 22 participants (63.6%) incorrectly categorised all 12, or almost all (11), of the irregular strings, and another two participants incorrectly categorised two-thirds. In the shapes and the target search tasks the highest proportion of irregular string incorrect categorisations was two-thirds and one-quarter respectively, with most participants incorrectly categorising less than this. However, in the shapes task 8 participants (36%) made at least twice as many errors to the inconsistently placed as to the consistently placed differing shapes whereas 15 participants (65%) made at least twice as many errors to the target present, inconsistent position strings as to the target present, consistent string types in the target search task.

³ Richardson (2011) suggests that Cohen’s benchmarks of effect sizes in partial eta-squared are: small - .0099, medium - .0588, large - .1379

4.3.2 Response times

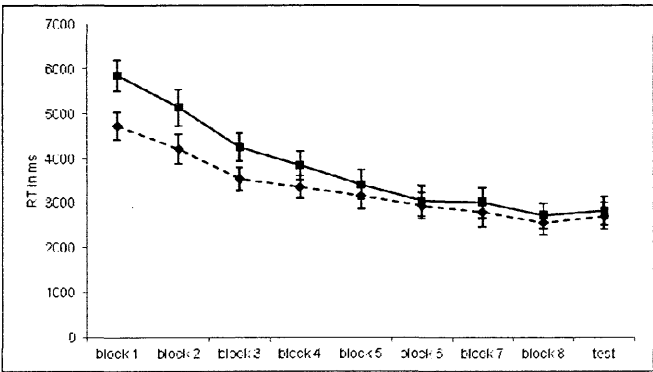
There was no significant correlation between overall mean RT and mean error rate in training in any task, (multiple-triplet task $r(20) = -0.036$, $p = 0.875$; shapes $r(20) = -0.117$, $p = 0.605$; target search task $r(21) = -0.229$, $p = 0.292$) suggesting no speed-accuracy trade-off occurred.

Figure 4.1 shows that response times decreased over the course of practice, indicating that overall participants got faster. Responses to correct stimuli were slower than to incorrect stimuli, although the RTs for correct and incorrect stimuli converged in the multiple-triplet and target search tasks. This seems to reveal a greater speeding for the correct stimuli over and above the speeding due to practice.

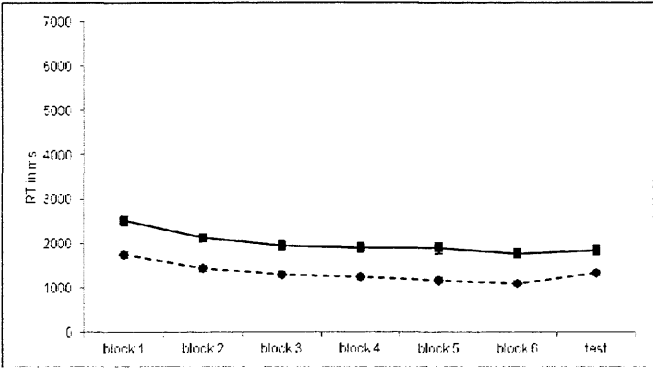
Figure 4.1: change in response times over the course of each task. Error bars represent the standard error of the means

Key: solid line – correct stimuli, broken line – incorrect stimuli

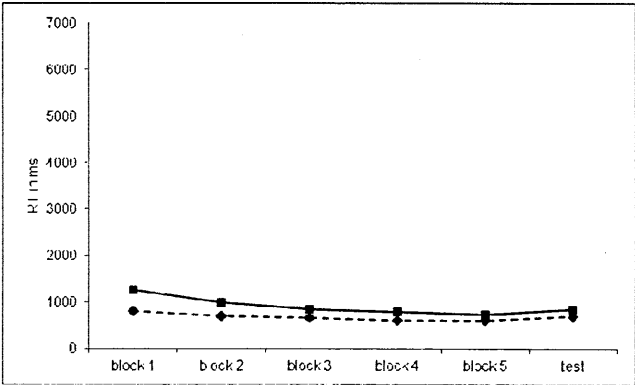
a) Multiple-triplet



b) Shapes



c) Target search



Separate repeated measures ANOVA by Block for each task (Table 4.3) showed there was a significant decrease in overall RTs during training for all tasks, and that the effect was large for all tasks, indicating that participants got faster.

Table 4.3: ANOVA results for response times in each task, by Block

Multiple-triplet	Over training (Blocks 1-8)	$F(7,147) = 42.4$, $MSE = 45403977$, $p < 0.001$, $\eta_p^2 = 0.669$
	Final training Block – test Block	$F(1,21) = 1.32$, $MSE = 255059$, $p = 0.263$, $\eta_p^2 = 0.059$
Shapes	Over training (Blocks 1-6)	$F(5,105) = 48.07$, $MSE = 2419007$, $p < 0.001$, $\eta_p^2 = 0.696$
	Final training Block – test Block	$F(1,21) = 12.2$, $MSE = 233384$, $p = 0.002$, $\eta_p^2 = 0.367$
Target search	Over training (Blocks 1-5)	$F(4,88) = 63.63$, $MSE = 1045185$, $p < 0.001$, $\eta_p^2 = 0.743$
	Final training Block – test Block	$F(1,22) = 25.8$, $MSE = 120403$, $p < 0.001$, $\eta_p^2 = 0.54$

In the multiple-triplet task there was no significant increase in RT between the final training block and the test block, suggesting that participants did not alter their processing speed in the test block. There was a significant increase between the final training block and the test block in both the shapes task and the target search task. This slowing down suggests that participants reverted to fuller checking of the

stimuli. The RTs were slower for the multiple-triplet task, reflecting the counting-through-the-alphabet required for each triplet.

4.3.3 “String-length effect”

One of the indicators of Information Reduction is an increased speeding in trials using longer strings or stimuli containing more shapes compared to the shorter ones over the course of the task. This can be ascertained by computing the regression slopes coefficient for ‘string length’ per participant and block and then subjecting these to a one-way repeated measures ANOVA by Block.

For correct strings in the multiple-triplet task there was a significant reduction in the slopes during training (Blocks 1-8), $F(7,147) = 16.68$, $MSE = 1949802$, $p < 0.001$, $\eta_p^2 = 0.443$. For incorrect strings there was also a significant reduction in slopes during training (Blocks 1-8), $F(7,147) = 3.29$, $MSE = 128037$, $p = 0.017$, $\eta_p^2 = 0.135$. One reason for this may be that participants were not initially terminating their evaluation when the error was encountered, but were checking more of the string, this being contrary to previous suggestions (Haider & Frensch, 1996). There was no significant increase in the slopes between the final training block and the test block for either correct or incorrect strings, $F(1,21) = 1.28$, $MSE = 17468$, $p = 0.27$, $\eta_p^2 = 0.058$, and $F < 1$ respectively. This was consistent with the high number of irregular strings incorrectly categorised, indicating that Information Reduction had occurred and only the initial triplet was being checked.

For matching shapes a significant reduction in slopes was found during training (Blocks 1-6), $F(5,105) = 9.37$, $MSE = 109312$, $p < 0.001$, $\eta_p^2 = 0.309$. For differing shapes there was also a significant reduction in slopes during training (Blocks 1-6), $F(5,105) = 5.67$, $MSE = 46694$, $p = 0.001$, $\eta_p^2 = 0.213$, which was expected since the boxes cannot be processed in a linear fashion and so initially a

varying number of comparisons would be made before finding the ‘incorrect’ shape. For matching shapes there was not a significant increase in the slopes between the final training block and the test block, $F < 1$, but there was a significant increase in the slopes between the final training block and the test block for differing shapes, $F(1,21) = 22.6$, $MSE = 147028$, $p < 0.001$, $\eta_p^2 = 0.518$. The lack of a significant increase in slope for matching shapes was unexpected, given that many of the irregular stimuli were spotted, since increased checking would have been anticipated as a differing shape was not found at the expected position.

In the target search task there was a significant decrease in the coefficient of the regression slopes for target absent strings during training (Blocks 1-5), $F(4,88) = 17.47$, $p < 0.001$, $MSE = 76173$, $\eta_p^2 = 0.443$. There was not a significant decrease in the coefficient of the regression slopes for target present strings during training (Blocks 1-5), $F(4,88) = 2.2$, $p = 0.123$, $MSE = 5066$, $\eta_p^2 = 0.091$, as would be expected, since processing can cease as soon as the target is found. There was a significant increase in slopes between the final training block and the test block for both target absent and target present strings, $F(1,22) = 14.52$, $p = 0.001$, $MSE = 15749$, $\eta_p^2 = 0.398$, and $F(1,22) = 24.71$, $MSE = 10986$, $p < 0.001$, $\eta_p^2 = 0.529$ respectively. The increase in slopes in the test block for target absent strings would be expected if participants noticed that the target was occasionally located later in the string and therefore checked the whole string when a target was not found at position two, however, it would not be expected for target present strings.

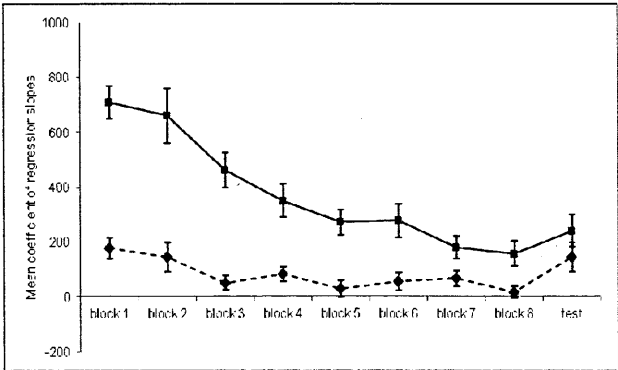
The effect size for the change in regression slope over the course of training for correct strings (multiple-triplet task), matching shapes (shapes task) and target absent strings (target search task) was large in all cases, suggesting that much of the variance could be explained by an increased speeding for the ‘longer’ stimuli.

Figure 4.2 shows that in all three tasks the mean of the regression coefficient for each block was higher for the ‘correct’ stimuli than for the ‘incorrect’ and never reduced to the same level over the training blocks, suggesting that reduction was not complete, at an aggregate level. However, this may conceal what was occurring at an individual level. For instance, in the multiple-triplet task if analysis is restricted to the 14 who, by their error rate, showed no indication of having noticed the irregular strings, then the slopes for incorrect and correct strings converge fully at block 7.

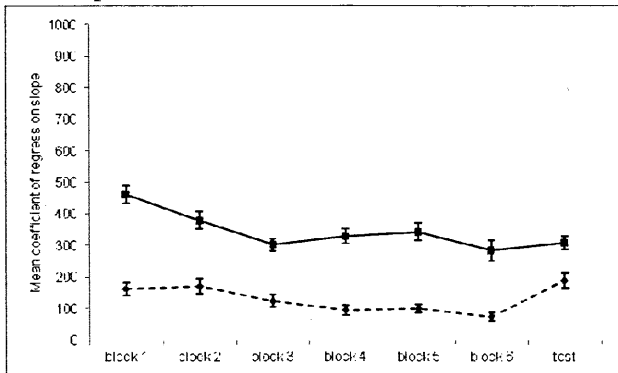
Figure 4.2: The change in coefficient of regression slopes plotted by block for the different stimuli types in all the tasks (error bars represent the standard error of the means)

Key: solid line - correct stimuli, broken line - incorrect stimuli

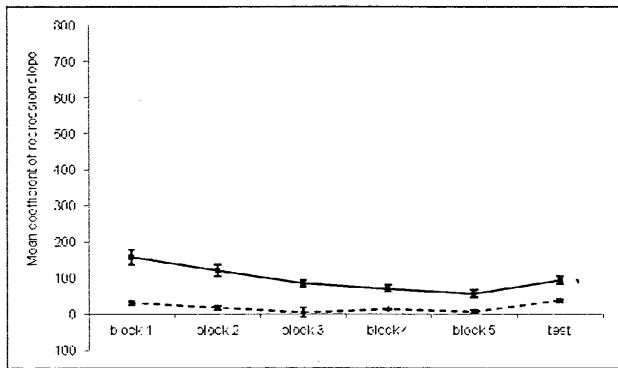
a) Multiple-triplet



b) Shapes



c) Target Search



It is also noticeable that the slopes for both matching and differing shapes were higher at the end of training than those in the other tasks, which may indicate that processing did not cease once the relevant location had been checked, even if it contained a differing shape.

One pattern that would be consistent with individuals using Information Reduction is if the mean coefficient of the regression slopes for 'correct' stimuli over the final two training blocks correlates with the error rate for 'irregular' stimuli in the test block. Participants with the lower slopes at the end of training should have the greatest number of errors to 'irregular' stimuli, giving a negative correlation.

For the multiple-triplet task this correlation was significant, $r(20) = -0.78$, $p < 0.001$, but for the shapes and the target search tasks it was not, ($r(20) = -0.17$, $p = 0.44$ and $r(21) = 0.22$, $p = 0.32$ respectively). For these two tasks this probably reflects the fact that although a significantly larger number of errors were made to the 'irregular' stimuli in the test block, all participants spotted most of them. Figure 4.3 shows scatterplots of these two measures with levels of awareness, from the questionnaires, for the three tasks.

4.3.4 Post-task questionnaires

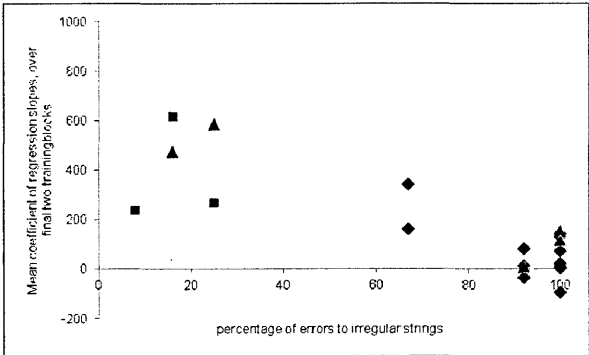
Based on the answers to all the questions the responses were coded into "explicitly aware/used Information Reduction strategy", "explicitly aware, continued checking irrelevant elements", and "did not verbally express regularity", relating to awareness of the regularity of positioning and use of an Information Reduction strategy. An example of the first was: "Whether it was right or wrong could be decided by the second letter. I only looked at the first 2 letters regardless of how long the string was" and an example of the second was "I noticed that the error was always at the beginning but I thought that might be a way of lulling us into a 'false

sense of security’ so always checked anyway”. The coded responses are shown on the scatterplots in Figure 4.3.

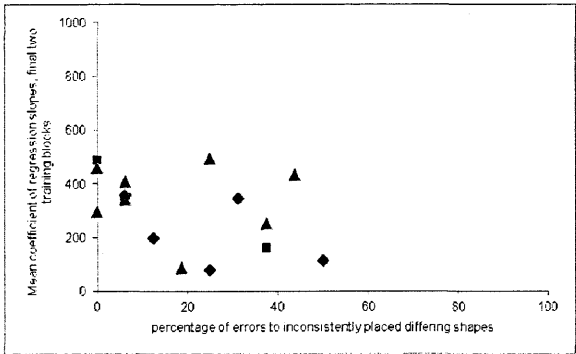
Figure 4.3: Scatterplots showing the mean coefficient of regression slopes over the final two training blocks against the percentage of errors to the ‘irregular’ stimuli, indicating categorisation from the questionnaire

Key ◆ - explicitly expressed regularity and indicated use of Information Reduction strategy
 ■ - aware of regularity, but continued checking irrelevant elements
 ▲ - did not verbally express regularity
 X - other strategy indicated

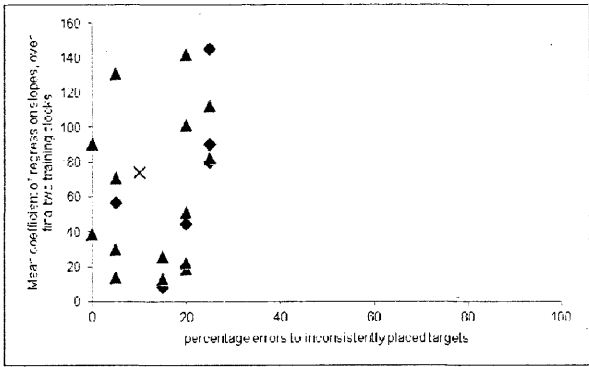
a) Multiple-triplet task



b) Shapes task



c) Target Search task



It can be seen that in the multiple-triplet task the verbal reports do mainly distinguish ‘reducers’ from ‘non-reducers’, where ‘reducers’ are those with low slopes and high errors. However, three people who appeared to be unaware of the regularity were acting as if reducers, which is inconsistent with the proposal that Information Reduction is a consciously adopted strategy. The picture is more mixed for the shapes task where the data show that no participant was fully reducing and half the participants showed no explicit awareness of any regularity. It could be surmised that partial reducing occurred, with those who indicated use of Information Reduction being amongst those with the higher number of errors and lowest slopes. The picture is also mixed for the target search task, where all participants had low slopes and the majority showed no explicit awareness of the regularity, but again it would appear that some partial reduction was occurring. There are no published criteria for assessing whether partial reduction has occurred, or how this might manifest in the participants’ self-report. Some questionnaires stated that the regularity was checked first and then other checking occurred, some or all of the time, and this may be evidence of partial reduction.

4.4 DISCUSSION

From the significantly larger number of errors made to ‘irregular’ stimuli and the significant reduction in slopes for ‘regular correct’ stimuli it would appear that Information Reduction occurred in all three tasks. This supports the hypothesis that Information Reduction, as determined by these measures, would be seen in these new, analogous, tasks. The results suggest that Information Reduction can be seen at an aggregate level in a variety of cognitive laboratory tasks, providing evidence to support Haider and Frensch’s assertion that it is a general learning process. However, for the shapes and target search tasks all the participants noticed the change in regularity in the test block, whereas only a few did so for the multiple-

triplet task. This suggests that in the former tasks Information Reduction had not been fully adopted, which is at odds with Haider and Frensch's suggestion that the strategy is applied consistently. However, many participants in these two tasks appeared unaware of the regularity, so it could be that Information Reduction is only used consistently once some conscious awareness has developed. This latter position would be compatible with the Unexpected-Event hypothesis (Frensch et al., 2003).

In terms of determining whether reducers could be distinguished from non-reducers, this was the case for the multiple-triplet task, with 64% classified as reducers, but not for the shapes or target search tasks. Most of those in the multiple-triplet task identified as reducers from their data could also be identified as such from their self-reports, although in a few cases the participant showed no awareness of the regularity or having changed their processing. The figure of 64% reducers in the multiple-triplet task (22 participants, with 480 training trials) compares to approximately 41% found by Haider and Frensch (1999a) in the relevant-first condition and 55% in the relevant-last condition of the Alphabet Verification task (22 and 23 participants respectively, with 700 training trials). Whilst the number of participants is small in both Haider and Frensch's experiment and the one reported here, the results point towards the number of reducers varying from task to task, although it is possible that task differences might be confounded with differences in the amount of practice. The multiple-triplet task required participants to carry out several calculations for the longer strings and it would appear to be more efficient to use Information Reduction for this task than the Alphabet Verification task, where all strings incorporate a single calculation. Overall, the results from all three tasks are suggestive of Information Reduction being differentially adopted depending on characteristics of the tasks.

Although it was not possible to determine a number of ‘reducers’ in the shapes and target search tasks, the aggregate data suggested Information Reduction had occurred and some participants indicated usage in their self-reports. It may be that it would require more practice for Information Reduction to become fully established in these tasks. It appeared that a number of people were partially using the strategy but how many and to what extent could not be quantified. It is possible that participants learned where to look initially, and if they found a differing shape or target letter ceased checking, but for the matching shapes or target absent strings tended to continue with some level of checking and thus spotted many of the irregular items in the test block. The results from all three tasks point towards a basic classification of four ‘types’ of people: aware users who discover and use the Information Reduction strategy; aware non-users who discover but choose not to use it for some reason; non-aware users who are apparently not aware of the regularity but still show signs in their data of usage; and non-aware non-users.

Since all participants in the shapes and target search tasks noticed some of the ‘irregular’ stimuli in the test block then it would appear that no-one is an ‘always-reducer’, using the strategy exclusively whenever they spot a regularity. The variation in use between tasks also suggests that there is not a constant proportion of people who are reducers. Some self-reports suggested awareness of the regularity but a decision not to exploit it. The number of ‘reducers’ varying from zero upwards and the existence of ‘deliberate non-reducers’ supports the idea that using Information Reduction is a conscious decision. However, the fact that some reducers were unable to verbalise the strategy, the possibility of partial reduction and the fact that the data for some ‘deliberate non-reducers’ also pointed towards partial usage, suggest that adoption of Information Reduction is not necessarily an all-or-nothing conscious

move by participants and that there may be some automaticity involved, indicating it is more complex than hypothesised by Haider and Frensch.

There are a number of possible reasons, which could exist in combination, why the numbers using Information Reduction differed across the tasks. Firstly, both the shapes and target search tasks were processed more quickly than the multiple-triplet task indicating that they were easier tasks. Doane et al. (1999) found that the strategy used varied with the difficulty of the task. They concluded that an Information Reduction-like strategy had occurred in the difficult version, and the current results tally with that. Secondly, the participants were more likely to notice the change in regularity in the test blocks for the shapes and target search tasks than for the multiple-triplet task, and this could be related to how much of the rest of the stimulus was in the focal area or was perceived. Alternatively it may be related to the ease of the task, or it may be that Information Reduction requires more practice in these tasks before becoming fully established. Thirdly, it may be that 'full' reduction is more likely to be seen when there is some sort of calculation needed, as in the multiple-triplet task and Alphabet Verification task, rather than when the task is purely visual, as in the shapes and target search tasks. Fourthly, instance learning may be involved. With both the multiple-triplet task and the Alphabet Verification task the initial triplet occurs a number of times within each block. If each of these becomes an instance, even though the rest of the stimulus may vary, then each can create many traces (Logan, 1988) or strengthen the representation (Rickard, 1997), increasing the chance of direct memory retrieval of the response needed. The structure of the shapes task meant that instances were not repeated within blocks, decreasing the chance of direct response retrieval. Where the required response is directly retrieved then processing of any other parts of the stimulus may be less likely to occur, encouraging the development of Information Reduction.

Doane et al (1999) explain their Information Reduction-like results in terms of a synthesised data-driven model of automaticity incorporating both rule compilation and instance learning (Anderson et al., 1997). Lee and Anderson (2001) suggest that improvements in the speed of execution of different elements of a task are due to different mechanisms, some of which are due to attentional shifts, i.e. reducing fixation time, which occur below the level of awareness. Some of the participants in our experiments did not appear to be aware of the potential strategy, although they may have been using it. Proponents of the Information Reduction model reject the notion that theories of automaticity are compatible with the top-down conscious processing observed in the Alphabet Verification task (Gaschler & Frensch, 2007). Instead they favour the idea that sometimes strategy change occurs as a result of a continuous, implicit, data-driven and not verbally expressible mechanism and sometimes as a result of abrupt, explicit, top-down and verbally expressible processing. The idea that the learning develops implicitly and then becomes available to conscious awareness, as the Information Reduction hypothesis would suggest, does explain some of the results from this experiment, such as the presence of non-aware users. However, it is not clear why those who become aware of a shortcut to processing should make a conscious decision not to use it. For some, as with the questionnaire extract quoted above (section 4.3.4), it may be related to knowledge of being in a psychology experiment and belief that it is necessary to maintain vigilance in case of some 'catch'. For others it may be that the instruction at the start, that errors could occur anywhere, and the instruction to be accurate as well as fast, kept them from 'letting go' (Hoyndorf & Haider, 2009).

Due to the limited number of potential participants for the rest of the experiments it was decided that only two tasks could be carried forward. The string-length effect, as measured in the Block 1 regression slopes, was biggest in the

multiple-triplet task and shapes task and these both showed a greater range of error rate in the test block. The existence of the string-length effect in all tasks indicates that all have potential for Information Reduction to occur and the size of the coefficient does not relate to how much additional speeding may be achieved by using the strategy. However, the combination of overall fast RTs even in the first block, low slopes and low error rates in the target search task suggests that it would have less sensitivity for detecting changes in the number of people using Information Reduction due to other manipulations. Additionally, this task had previously been used in a variety of experiments (Edmunds, 2005). Consequently, the multiple-triplet and shapes tasks were selected for further experiments. The next two experiments, detailed in chapters 5 and 6, start to explore the third research question, of whether alterations to training conditions change the number of people using Information Reduction.

Chapter 5 EXPERIMENT 2

FEEDBACK MANIPULATION⁴

5.1 INTRODUCTION

Having established that Information Reduction occurs in the multiple-triplet task and the shapes task, with different numbers of participants using it in each, this experiment sought to test if changing the training conditions would affect the numbers using it. It should be possible to affect a consciously-controlled strategy by alterations to external conditions, whereas Instance theory (Logan, 1988) would predict no change since the faster processing derives from a subconscious switch from using the steps of an algorithm to direct memory retrieval as a result of encounters with the specific stimuli. Similarly, the Production rules theory (Anderson, 1987) would not predict any change, since the productions to be used to carry out the task would be the same.

Skill training often involves feedback, although the amount and type can be variable, even over the duration of learning. In the Alphabet Verification task experiments feedback has been applied in a number of ways: either on a trial-by-trial basis (Haider & Frensch, 1996), at the end of each block (Haider & Frensch, 1999b), or not at all (Haider et al., 2005). The initial series of experiments (Haider & Frensch, 1996) gave feedback in two ways: participants were informed of errors in their verification as they occurred by a screen prompt and an audible tone, both during the training blocks and during the transfer block, except for the transfer block in the no-feedback condition in experiment 2; in addition participants were informed of

⁴ The experiment reported in this chapter was included in the paper: Information Reduction—More than meets the eye? (2015), Nancy E. Rowell, Alison J. K. Green, Helen Kaye & Peter Naish, *Journal of Cognitive Psychology*, 27:1, 89-113, DOI:10.1080/20445911.2014.985300

their error rate and mean response time per block, on a block-by-block basis. The same sort of feedback was employed for the triplet-position manipulation (Haider & Frensch, 1999a), although in the test block only half of the participants in the relevant-first and relevant-last conditions received feedback. However, in the eye-tracking experiment reported in the same paper, feedback was only given at the end of each block, as mean response times and error rates for the block. This was also the way feedback was given in the speed-accuracy experiments (Haider & Frensch, 1999b), with mean RTs followed by accuracy in the speed conditions and the reverse in the accuracy conditions. The later experiments, manipulating string frequency (Gaschler & Frensch, 2007; Gaschler & Frensch, 2009), gave trial-by-trial feedback on errors during training but not during test, as well as end-of-block feedback. In general no rationale has been given either for the use of feedback or the variations in particular experiments, although one could speculate that giving trial-by-trial error feedback in experiments emphasising speed may distract the participants and cause slowing in order to be accurate. In the inconsistent training experiment (Haider et al., 2005), feedback may have been removed so as not to alert the participants to the manipulation. From the results of the various experiments it would seem that Information Reduction is adopted whether or not trial-by-trial feedback is given. However, it is difficult to compare across the experiments due to other differences in procedures.

Edmunds (2005) ran a small-scale pilot to test the effect of having only end-of-block feedback instead of trial-by-trial. Results suggested that fewer adopt Information Reduction in the Alphabet Verification task with only end-of-block feedback, or that those who adopt do so less completely. Thus it could be surmised that reinforcement of a correct response in which the participant had used Information Reduction, which essentially occurs with lack of an error prompt, would

encourage the further use of the strategy. If this is the case it would help confirm its theorised conscious nature.

Experiment 1 (Chapter 4) gave trial-by-trial visual feedback on errors during training but not during test. However, some participants commented on the lack of error prompts there, and this may have alerted them to the block being different, thus increasing vigilance and noticing of the irregular stimuli. Additionally, in the shapes task, there was a doubling of errors to differing shapes from the final training block to the test block. The reason for this is not known, but this anomaly may have arisen because feedback was removed at this point. A line length estimation task carried out by Judd in 1905 (cited in Kluger and DeNisi, 1996) found an increase in errors when switching from no feedback to feedback. However, there is contradictory evidence from e.g. Arps (1920). Possible reasons for this may be differences in the order of giving and removing feedback or the type of task. It was considered that removal of feedback from some of the training trials in the current tasks, to enhance contextual similarity between the conditions in practice and retention (the test block), may be beneficial.

It has been shown that feedback does not always improve learning (Kluger & DeNisi, 1996). For instance, it has been suggested that feedback can positively or negatively affect motivation, resulting in an increase or decrease in attempts to perform correctly, and/or it can cause a shift in attention. In the type of tasks used in Information Reduction research error notification may cause attention to be redirected to consider the whole stimulus, negating any reduction occurring. In their meta-analysis of feedback interventions Kluger and DeNisi found that feedback on memory tasks is more effective than feedback on tasks requiring rules to be followed, which has implications for Information Reduction tasks that may involve both memory (e.g. instance acquisition) and rules e.g. the algorithm in the Alphabet

Verification task and multiple-triplet task, or even the Information Reduction rule itself, once noticed.

In motor-skill learning, feedback can create a dependency, with performance breaking down without it (Buchanan & Wang, 2012). Buchanan and Wang suggest that the motor representation develops better when relying on internal proprioceptive feedback than on external 'knowledge of results', hence the performance decrement when an apparently learned task is performed without feedback. One way to prevent this dependency is to reduce the amount of feedback given (Winstein & Schmidt, 1990). Feedback early on is thought to help the participant achieve the required responses, but a reduction later in the learning process is not considered detrimental and may even be beneficial. Many laboratory tasks have both a perceptual and motor representation, for instance when learning a sequence of key presses in response to visual stimuli, and it has been hypothesised that these are learned independently by two different cortical systems (Hikosaka et al., 1999). Spatial learning relies on attention and working memory and tends to occur quickly and be flexible, whereas motor learning takes longer, being acquired with practice. The tasks used in this set of experiments require learning of the appropriate movement response for the 'correct' and 'incorrect' keys for each of the stimuli and this aspect may develop more readily if feedback is not given.

Considering these previous results it is unclear if trial-by-trial feedback is helpful or required throughout the whole training period. Thus it was decided that for Experiment 2 trial-by-trial feedback would cease halfway through the training phase, and participants were informed of this. If removal of feedback for the test block in Experiment 1 caused an overall increase in errors then an earlier change should shift the increase to the point of removal. Having feedback for the first half of the experiment means that if the regularity has been noticed and Information

Reduction used then it will have been reinforced for 240 trials, but it is not clear whether this is sufficient to encourage the same levels of adoption of the strategy as Experiment 1. It was anticipated that participants who had discovered and implemented the strategy prior to removal of feedback would continue to use it, although they may initially revert to full checking in case it was no longer valid. Those who discovered the regularity after the removal of feedback should adopt the Information Reduction strategy from then on.

5.2 METHOD

5.2.1 Participants

There was a total of 47 participants, 18 students of the Open University undertaking a psychology module and 29 members of the Open University Virtual Participants Panel, who were mainly staff and psychology students of the Open University. No participant had performed in Experiment 1. All participants carried out only one task. 10 were male and 37 were female. There were 25 (6 male) in the shapes task, and 22 (4 male) in the multiple-triplet task. Their ages ranged from 22-56, mean age 41.

5.2.2 Design and materials

For both the multiple-triplet and shapes tasks these were identical to Experiment 1 (Chapter 4).

5.2.3 Procedure

The procedure was identical to Experiment 1 for the first 240 training trials. At this point, participants were informed that feedback on errors would cease. All stimulus screens from that point until the experiment was completed were followed by a blank screen for 500ms – this was 240 further training trials and then the test

block. The test block had 60 trials for the multiple-triplet task and 80 for the shapes task.

5.3 RESULTS

5.3.1 Accuracy

Participants who had more than 10% per block errors throughout training were not included in the analysis. No participants were excluded from the multiple-triplet task analysis but data from three were removed from the shapes task analysis, leaving 22 participants in each.

Table 5.1 shows that similar numbers of errors were made to the ‘regular’ strings and shapes in the final training block and the test block. Over four times more errors were made to the consistently placed differing shapes than the matching shapes in both blocks. Whilst the feedback manipulation removed the disparity between the final training block and the test block in this task for consistently placed differing shapes, this can be accounted for by the fact that there were more errors to this stimulus type at the end of training. In other words, the error rate had not declined as much over training as in Experiment 1. There was no increase in errors when the feedback was removed. In the multiple-triplet task there were fewer errors made overall than in Experiment 1.

For both tasks more errors were made to the irregular strings and inconsistently placed shapes, but whilst the error rate for inconsistently placed shapes was similar to Experiment 1, there was a considerable reduction in errors to irregular strings. Six participants made no errors and seven participants made just one error to these, suggesting that the cessation of feedback made the participants in this task more cautious overall.

Table 5.1: Overall error rates in final training block and test block by stimulus type

Task	'String type'	Final training block	Test block
Multiple-triplet	Correct strings	2.9%	2.4%
	Incorrect strings	1%	2.3%
	Irregular strings	-	15.9%
Shapes	Matching shapes	0.6%	1.1%
	Differing shapes, consistent position	4.5%	5.9%
	Differing shapes, inconsistent position	-	18.8%

A one-way repeated measures ANOVA (String Type: regular correct, regular incorrect and irregular) on error rates for the test block showed a significant difference between the trial types for each task. For the multiple-triplet string types, $F(2,42) = 5.55$, $MSE = 2629$, $p = 0.027$, $\eta_p^2 = 0.209$, with the difference lying between the 'regular' and 'irregular' strings (pairwise comparisons: regular correct vs regular incorrect $p = 0.874$; regular correct vs irregular $p = 0.034$; regular incorrect vs irregular $p = 0.021$). For the shapes task different shape types, $F(2,42) = 19.92$, $MSE = 2884$, $p < 0.001$, $\eta_p^2 = 0.487$ with each significantly different from the others (pairwise comparisons: regular correct vs regular incorrect $p = 0.001$; regular correct vs irregular $p < 0.001$; regular incorrect vs irregular $p = 0.001$). Again the effect sizes in both tasks are large, suggesting that some of the variance in the error rates is explained by the difference in the stimuli types. For the multiple-triplet task the effect is smaller than Experiment 1, where the effect size was .785, but is very similar for the shapes task (.477 in Experiment 1).

In the multiple-triplet task 2 of the 22 participants (9%) incorrectly categorised all 12 or almost all (11) of the irregular strings. In the shapes task the highest proportion of incorrect categorisations was just over half of the irregular strings,

however 7 out of the 22 participants (32%) made at least twice as many errors to the inconsistently placed as to the consistently placed differing shapes, which may indicate that some degree of Information Reduction had occurred.

5.3.2 Response times

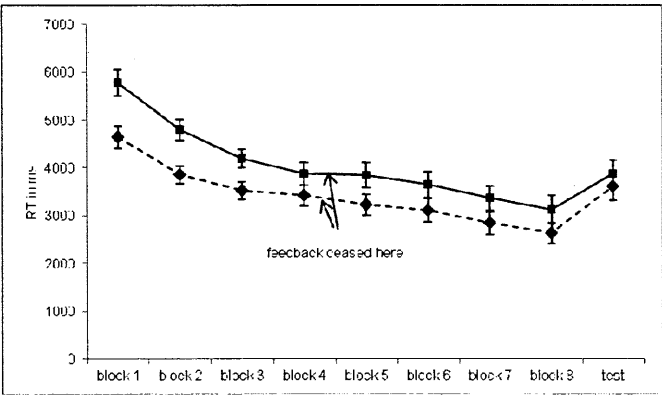
In neither task was there a significant correlation between overall mean RT and mean error rate in training, (multiple-triplet $r(20) = 0.038, p = 0.867$; shapes $r(20) = -0.153, p = 0.497$) suggesting that there was not a speed-accuracy trade-off.

Figure 5.1 shows that response times decreased during each task, with an increase in the test block, particularly in the multiple-triplet task.

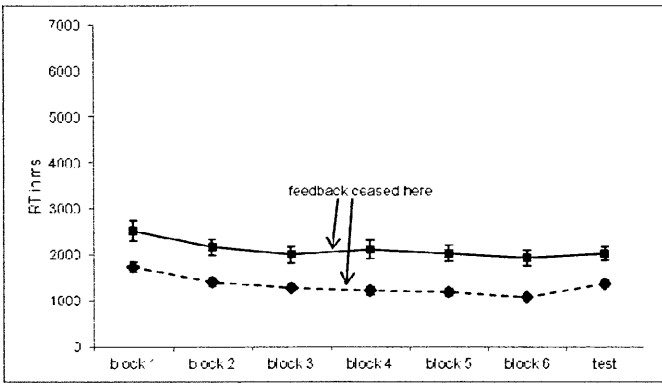
Figure 5.1: change in response times over the course of each task. Error bars represent the standard error of the means

Key: solid line – correct stimuli, broken line – incorrect stimuli

a) Multiple-triplet



b) Shapes



The RTs for correct stimuli were slower than those for incorrect. Overall RTs were slower for the multiple-triplet task. The RTs for correct and incorrect strings did

begin converging in the first half of the experiment, when feedback was being given, but once the feedback ceased so did the convergence.

Separate repeated measures ANOVA by Block for each task (Table 5.2) showed there was a significant decrease in overall RTs during training and a significant increase in RT between the final training block and the test block, with large effect sizes. RTs for matching shapes increased slightly when feedback ceased, suggesting that the notified change caused more careful checking. This was more noticeable at the individual level with 10 participants (45%) showing an increase in RT at this point, in two cases to above the mean RT for their first block, whilst the others continued to show a steady decline in RT.

Table 5.2: ANOVA results for response times by Block

Multiple-triplet	Over training (Blocks 1-8)	$F(1,147) = 44.78$, $MSE = 51258029$, $p < 0.001$, $\eta_p^2 = 0.681$
	Final training Block – test Block	$F(1,21) = 37.98$, $MSE = 7443453$, $p < 0.001$, $\eta_p^2 = 0.644$
Shapes	Over training (Blocks 1-6)	$F(1,105) = 21.79$, $MSE = 2189050$, $p < 0.001$, $\eta_p^2 = 0.509$
	Final training Block – test Block	$F(1,21) = 22.25$, $MSE = 417795$, $p < 0.001$, $\eta_p^2 = 0.514$

5.3.3 “String-length effect”

The regression slopes coefficient for ‘string length’ per participant and block were computed and subjected to a one-way repeated measures ANOVA by Block. This shows whether the RT for longer ‘strings’ decreased reliably more than that for shorter ‘strings’ which would be indicative of a shortcut being applied to the longer ‘strings’. The change in coefficient of regression slopes for both tasks is shown in Figure 5.2.

For correct strings in the multiple-triplet task there was a significant reduction in the slopes during training (Blocks 1-8), $F(7,147) = 16.13$, $MSE = 1180079$, $p < 0.001$, $\eta_p^2 = 0.434$ and a significant increase in the slopes between the final training block and the test block, $F(1,21) = 14.58$, $MSE = 948463$, $p = 0.001$, $\eta_p^2 = 0.41$. The large effect sizes, which for training was of the same order as Experiment 1, suggests that some of the variance could be explained by an increased speeding for the longer strings during training and also a greater slowing in the test block. For incorrect strings there was no significant reduction in the regression slopes over the course of training (Blocks 1-8), $F(7,147) = 1.46$, $MSE = 23897$, $p = 0.187$, $\eta_p^2 = 0.065$; however there was a significant increase in slopes between the final training block and the test block, $F(1,21) = 80.38$, $MSE = 1451571$, $p < 0.001$, $\eta_p^2 = 0.793$. Figure 5.2 shows that there was less convergence of the slopes for correct and incorrect strings than in Experiment 1. There would seem to have been some Information Reduction occurring in this task, but not to the same extent as in Experiment 1.

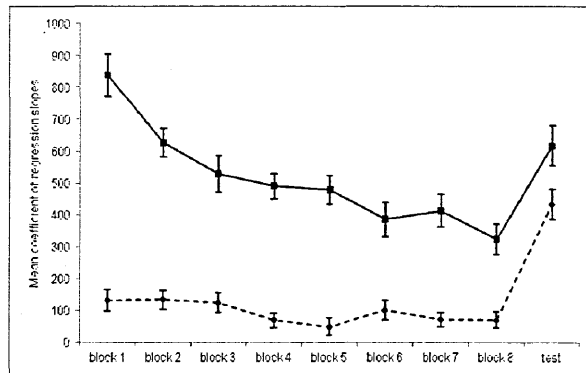
For matching shapes there was no significant decrease in regression slopes over the course of training (Blocks 1-6), $F < 1$, nor was there a significant increase in slopes between the final training block and the test block $F(1,21) = 1.52$, $MSE = 10432$, $p = 0.232$, $\eta_p^2 = 0.067$. There was an increase in slopes for matching shapes when feedback ceased, suggesting that some, at least, of the participants were disturbed by this change and reverted to full checking of the boxes. This increase is probably the reason that there was no significant decrease in regression slopes during training.

For differing shapes there was a significant reduction in the regression slopes over the course of training (Blocks 1-6), $F(5,105) = 3.29$, $MSE = 65889$, $p = 0.029$, $\eta_p^2 = 0.135$ and a significant increase in slopes between the final training block and the test block $F(1,21) = 19.43$, $MSE = 119085$, $p < 0.001$, $\eta_p^2 = 0.481$.

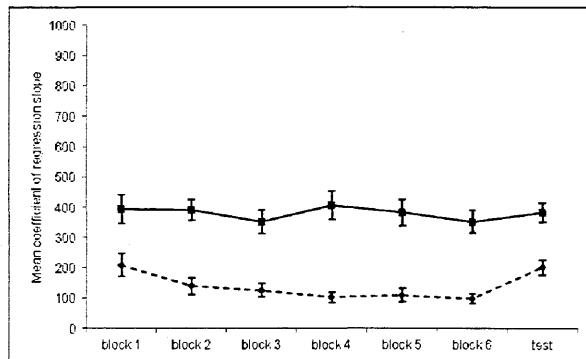
Figure 5.2: The change in coefficient of regression slopes plotted by block for the different stimuli types in both tasks (error bars represent the standard error of the means)

Key: solid line - correct stimuli, broken line - incorrect stimuli

a) Multiple-triplet



b) Shapes



The correlational analysis for the mean coefficient of the regression slopes for correct strings/matching shapes over the final two training blocks with the error rate for ‘irregular’ stimuli in the test block was almost significant for the multiple-triplet task, $r(20) = -0.418$, $p = 0.053$, and significant for the shapes task, $r(20) = -0.622$, $p = 0.002$. Scatterplots for these are shown in Figure 5.3, where it can be seen that there were two identifiable reducers (9%) in the multiple-triplet task. Once again there were no identifiable reducers in the shapes task, probably because all the participants noticed some of the irregular stimuli in the test block.

5.3.4 Post-task questionnaires

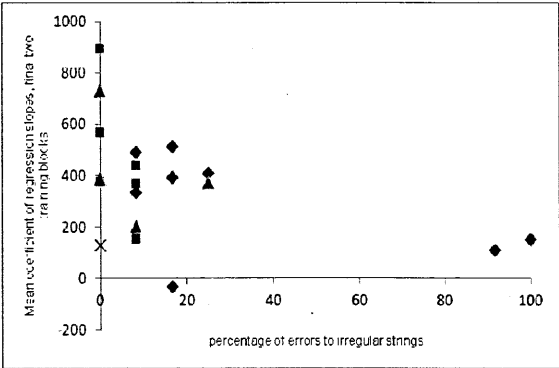
One questionnaire for the multiple-triplet task was not returned. The responses were coded as before and are indicated in Figure 5.3. For the multiple-

triplet task, the two participants already identified as reducers gave a self-report that showed they were aware of the regularity and used the strategy. Several other participants indicated in the questionnaire that although they were aware of the regularity and made some use of it, they also carried out some checks on the rest of the string, so that their slopes generally remained high and they spotted the change in the test block. For those who indicated that they were aware of the regularity but had not used it the slopes suggest that they may have done so until the point at which the feedback ceased. They showed no sign of returning to use it after a block or two of checking that the rule still held.

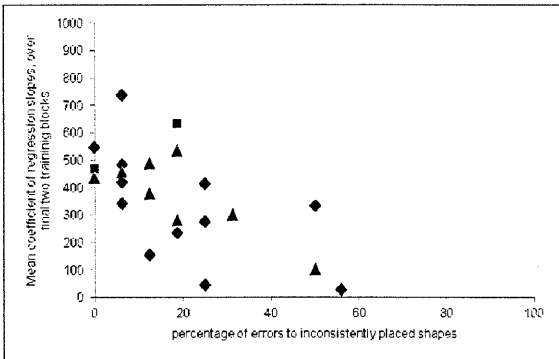
Figure 5.3: Scatterplots showing the mean coefficient of regression slopes over the final two training blocks against the percentage of errors to the ‘irregular’ stimuli, indicating categorisation from the questionnaire

Key ◆ - explicitly expressed regularity and indicated use of Information Reduction strategy
 ■ - aware of regularity, but continued checking irrelevant elements
 ▲ - did not verbally express regularity
 X - no questionnaire

a) Multiple-triplet



b) Shapes



In the shapes task the data show that no participant was fully reducing. Nearly half the participants showed no explicit awareness of any regularity in the questionnaire, although some may have been partially reducing, as suggested by their error rates. Once again it does seem that not all are sufficiently aware of their strategy use to be able to explicitly verbalise it. Nonetheless it could be surmised that some partial reducing occurred, with a number of participants who were aware of the regularity and indicating they made use of it also indicating a degree of residual checking.

5.4 DISCUSSION

This experiment was conducted to start investigating whether the numbers of participants using Information Reduction vary if the training conditions are altered. The change in coefficient of the regression slopes suggests that, for the multiple-triplet task and the differing shapes (although not the matching shapes), Information Reduction was occurring at the aggregate level. The error rate to irregular strings however, suggests that there was much less Information Reduction in the multiple-triplet task than Experiment 1, and this is reflected in the fact that only two participants could be identified as reducers from the scatterplot. For the shapes task, the amount of Information Reduction, as measured by the overall error rate to irregular shapes and visually from the scatterplot, appears similar to Experiment 1. Thus the two tasks seem to have been differentially affected by the removal of feedback halfway through training. Complete Information Reduction all but disappeared from the multiple-triplet task, whereas for the shapes task the manipulation merely seems to have slightly unsettled the participants, as shown by an increase in RT and slopes at the point it was removed. These results tend to rule out theories of automaticity as sole explanations for the processing occurring. If either instance learning (Logan, 1988) or creation of production rules (Anderson, 1987)

leads to Information Reduction, then there should have been the same level of reduction in both tasks as seen in Experiment 1, since the stimuli were identical, required the same processing and were seen for the same number of trials.

It has been suggested that Information Reduction is consciously and abruptly applied so that once the strategy has been noticed, it serves to change behaviour from that point onwards for all stimuli of the same type (Gaschler & Frensch, 2009; Haider & Frensch, 2002). Therefore it would be expected that anyone who had noticed the shortcut and had started to use it, before the feedback was removed, would continue to do so. There might be a short period where they revert to checking the whole stimulus after removal of feedback, but once satisfied that the rule still holds should re-implement the strategy. This does not seem to have occurred here. Although the slopes suggest that Information Reduction occurred throughout, it would seem that many of the 'reduction-aware' participants were carrying out checking of some entire strings (which might be termed 'partial reduction'), so the change in regularity in the test block was noticed. Additionally, inspection of individual slopes, for those indicating on the questionnaires that they had not used the strategy, suggests that a number of 'aware users' became 'aware non-users' on removal of feedback, deciding not to use the regularity for the rest of the experiment. This could indicate that use of Information Reduction is a consciously controlled process, as hypothesised. However, it also seems to be sensitive to changes in conditions and this is at odds with the idea that it is applied from the point at which it is noticed that a strategy can be used.

Comparing to previous experiments which have assessed the number of people using Information Reduction, the result for the multiple-triplet task in this experiment does seem to be an anomaly. The control experiment (Chapter 4) found 64% of the participants in the multiple-triplet task could be classified as reducers.

Haider and Frensch (1999a) gave feedback on errors throughout training in a triplet-position-altering experiment and found that 52% of those in the relevant-last condition and 41% of those in the relevant-first condition could be classified as reducers. Haider et al. (2005) gave no feedback at all in an inconsistent training experiment and found 63% of participants in the Always-regular condition could be classed as reducers, although they arrived at this result from analysis of RT-discontinuities of > 1 s between blocks. Edmunds (2005) found that using only end-of-block feedback resulted in less Information Reduction occurring in the Alphabet Verification task – whilst there was still a significantly higher error rate to irregular strings in the test block, the slopes did not decline significantly. So, when feedback is either fully present or fully absent, it would appear there are similar numbers who use the strategy. However, having intermittent feedback, either just at the end of each training block or, as in this experiment, having trial-by-trial feedback removed, seriously affects Information Reduction usage in a task where a computation is involved.

This anomaly, along with the differential results for the multiple-triplet and shapes tasks, may indicate that more than one mechanism is at work. The multiple-triplet task could involve either instance or working memory – a number of participant questionnaires revealed that memory strategies were being used, particularly when the triplet seemed to make a word. For instance, B(4)G looks like BAG and H(4)M looks like HAM, making it easy to remember that those are correct triplets. Without feedback people may not have been willing to rely on their memory for the desired response. Touron and Hertzog (2004a, 2004b) demonstrated that a change to a memory retrieval strategy was affected by confidence in memory ability. Kluger and DeNisi (1996) found that feedback on memory tasks was more effective than for tasks with rules to be followed and this suggests the multiple-triplet task

may be treated by participants as primarily a memory task. Thus even those who are aware of the regularity may choose not to use it without reinforcement for correct answers when an algorithm is involved.

With the shapes task, however, instance learning was less likely and use of working memory unlikely, since the combination of shapes and their configuration within the boxes was unique in each of the 80 stimuli in each block. Therefore, although the removal of feedback unsettled some of the participants, causing an increase in RT and slopes coefficient for matching shapes at that point, overall it does not seem to have affected the amount of Information Reduction seen. As with Experiment 1, there is no clear division between reducers and non-reducers in this task and nobody seemed to use the strategy completely, so that it was not possible to deduce the number of reducers. The aggregate data suggested that Information Reduction had occurred and the self-reports support this. Thus it would seem that it was only partially used by some participants. The current Information Reduction model, which proposes that either the strategy is abruptly and fully adopted for all stimuli at the same time (all) (Haider & Frensch, 2002; Gaschler & Frensch, 2009) or not adopted at all (nothing) would need to be extended to explain 'partial reduction'. How 'partial reduction' might manifest in processing is not known, and this could be differently in different people, or differently in the same person under different conditions. For example, it could be that some stimuli were fully processed whereas only the relevant portion was processed in others. It could be that random parts of some stimuli were processed (Haider & Frensch, 1999b).

Although there were no non-aware users in the multiple-triplet task, unlike Experiment 1, there were several in the shapes task whose slopes and error rates suggest they were using the strategy as much as those who indicated awareness of it. So this again calls into question whether it is necessary for conscious awareness for

Information Reduction to occur. Taken with the results from this experiment indicating that the number of people who adopt the Information Reduction is affected by the training conditions, and that the effect of variable training conditions is not equivalent across tasks, the evidence is starting to suggest that modifications are needed to the hypothesis put forward by Haider and Frensch.

The next chapter considers another alteration to the training conditions, in which speed is emphasised over accuracy, to examine the effect that this manipulation may have on numbers using Information Reduction.

Chapter 6 EXPERIMENT 3

EMPHASIS ON SPEED⁵

6.1 INTRODUCTION

The evidence from Experiments 1 and 2 suggests that Information Reduction usage varies with task and training conditions. The results also call into question whether it is an abruptly adopted strategy and possibly whether it is completely under voluntary control. Therefore this experiment sought to explore this further by examining the effect of altering another of the conditions that can vary in practice learning, i.e. the instructions given. If it is an automatic process, such as those mechanisms proposed by Logan (1988) or Anderson (1987), no change to the numbers using Information Reduction would be expected. In most experiments investigating Information Reduction participants are requested to be as fast and as accurate as possible, however there have been some where either speed or accuracy have been emphasised and in one case the time allowed for making a decision was reduced. Haider and Frensch (1999b) demonstrated that changing the instructions to stress either speed or accuracy affects the extent of reduction occurring, with Information Reduction being adopted more quickly under speed stress. However, it is not clear from their results whether more participants used the strategy, or if it were just that those who did adopted it more quickly. Haider et al.'s (2005) results suggest that more might use the strategy when subjected to speed pressure. In this experiment the main training blocks were interspersed with blocks where a smaller number of strings were used, with each string displayed for a limited amount of time. Results suggest 63% of participants in the Always-regular condition used

⁵ The experiment reported in this chapter was included in the paper: Information Reduction—More than meets the eye? (2015), Nancy E. Rowell, Alison J. K. Green, Helen Kaye & Peter Naish, *Journal of Cognitive Psychology*, 27:1, 89-113, DOI:10.1080/20445911.2014.985300

Information Reduction, as judged by a drop in RT of 1 second between blocks. This compares to 40-50% reported users in other experiments, although in those it was measured by the more standard methods of attenuation of the string-length effect and increased errors to irregular strings. A large change in RT is suggestive of a strategy being employed but does not indicate which strategy and thus the 63% could include participants who were not using Information Reduction.

Haider and Frensch previously concluded that people can modify their behaviour to some extent. In other words, that ignoring redundant information is a strategy that is under voluntary control, with participants choosing to use the strategy under speed instructions but choosing not to use it under accuracy instructions. An alternative explanation would be that Information Reduction is an automatic process which can be overridden by participants making a conscious decision to check the whole string in the accuracy conditions. It has been suggested that speed stress can increase the rate at which a task becomes automatic, although empirical evidence for this seems lacking (LaBerge & Samuels, 1974). If this is the case most of the results reported by Haider and Frensch, where the responses become faster more rapidly under speed stress, do not rule out either Anderson's (1987) or Logan's (1988) theories of automaticity, or Rickard's (1997) variation of Instance theory, although Haider and Frensch take them as indications that the Information Reduction strategy is under conscious control. Touron and Hertzog (2004b) suggest that the strategy shift from algorithmic processing to memory retrieval, which may be either conscious or unconscious, occurs when the benefits of retrieval are greater than the cost of memorisation of the instance. They demonstrated that manipulating display and memory set size in the noun pair look-up task resulted in an earlier move to a retrieval strategy, and considered that their results were compatible with the Component Power Law theory (Rickard, 1997).

It is known that people can consciously alter their response criteria depending on the demands of the task, being more liberal and checking less when the need is to be fast, at the expense of accuracy. This would seem to be borne out by Haider and Frensch's results for their Experiment 1 (1999b), where a large number of participants in the speed condition (15/41) were excluded from the analysis due to making more than 15% errors, a cut-off which was higher than that generally used, and was likely to leave more in the analysis than if the normal 10% had been employed. A slightly smaller proportion were excluded from the speed-accuracy and accuracy-speed conditions (9/40 and 8/41 respectively). This is in comparison with 3/45 being excluded in the accuracy condition. No data was given as to whether the errors were spread through all blocks or occurred predominantly in the speed-stress ones. It is reported that the remaining participants did not show a reliable speed-accuracy trade-off, however during the speed stress blocks this does seem to have occurred. In their Experiment 2, where the speed stress involved the strings being visible on screen for a reducing amount of time as well as instruction manipulation, even more participants were excluded for their high error rate: 13/21 participants in the speed condition, 8/21 and 5/21 in the speed-accuracy and accuracy-speed conditions. In the accuracy condition just one participant out of 20 was excluded. The relatively high numbers of people making more errors when under speed stress does bring into question the types of strategy, if any, being employed and does strongly suggest that the excluded participants were showing a speed-accuracy trade-off strategy. Haider and Frensch mention the possibility that under speed stress the participants may not have been 'reducing' by processing only the triplet but may have been reducing by randomly sampling parts of the string to determine their response, which would have decreased their accuracy. In this experiment no trial-by-trial feedback was given, complicating comparison with most other experiments.

Haider and Frensch do not give a reason for the absence of feedback. It is possible that immediate feedback on errors could counteract the instruction to focus on speed, since it reminds participants about accuracy.

Having found that only giving end-of-block rather than trial-by-trial feedback caused less Information Reduction to occur, Edmunds (2005) gave instructions that emphasised being as fast as possible in his inconsistent-training experiment and this had the desired effect in restoring 'normal' levels of Information Reduction in the 100% consistent condition. However, it is again not clear whether this was achieved by more people adopting Information Reduction or simply by it being more firmly established in those who did use it.

It would seem that further experiments to try and distinguish what the participants are doing when instructed to be as fast as possible would be useful. It may be that the same proportion use Information Reduction as in experiments where both speed and accuracy are instructed, but perhaps adopt it more quickly. Perhaps more might use Information Reduction, since this is a way to increase speed. Some of those who have not become aware of the regularity may use a speed-accuracy trade-off strategy instead. A first step towards distinguishing these possibilities would be to determine how many seem to be using Information Reduction under speed stress and to examine whether there is a speed-accuracy trade-off for participants who do not seem to be using Information Reduction. The experiment reported here investigated the effect of applying speed pressure, using only altered instructions. To enable comparison with Experiment 1, trial-by-trial feedback on errors was given in training but not in the test block. Based on the evidence from Haider et al. (2005) and from Edmunds (2005) the hypothesis was that more participants would adopt the strategy when requested to be as fast as possible.

6.2 METHOD

6.2.1 Participants

There was a total of 50 participants, 23 students of the Open University studying a cognitive psychology module and 27 members of the Open University Virtual Participants Panel, who were mainly staff and psychology students of the Open University. No participant had performed in Experiment 1 or 2. All participants carried out only one task. 9 were male and 41 were female. There were 24 (3 male) in the shapes task and 26 (6 male) in the multiple-triplet task. Their ages ranged from 18-60, mean age 42.

6.2.2 Design and materials

For both the multiple-triplet and shapes tasks these were identical to Experiment 1 (Chapter 4).

6.2.3 Procedure

Apart from the wording of the instructions the procedure was identical to Experiment 1, with 480 training trials, followed by the test block. At the start of the experiment participants were, as before, instructed: "Please be as fast and as accurate as possible but pay close attention to the strings as errors can occur anywhere." At the end of each block the participants were given feedback on their mean RT for the preceding block and encouraged to take a short break. At the start of the next block the participants were instructed: "Remember to be as fast as possible".

6.3 RESULTS

6.3.1 Accuracy

The analysis excluded participants with errors in training of 10% or greater for each trial block. In the multiple-triplet task four were excluded, leaving 22 participants' data, and in the shapes task four participants were excluded, leaving 20 participants' data. Those excluded actually had more than 15% errors, so that this experiment included all who would have been included with the 15% criterion used by Haider and Frensch (1999b).

Similar numbers of errors were made to the 'regular' strings and shapes in the final training block and the test block but more errors were made to the irregular strings and inconsistently placed shapes (Table 6.1). Fewer errors were made to irregular strings than in Experiment 1, but more than Experiment 2. However, for inconsistently placed differing shapes more errors were made than in both Experiments 1 and 2.

A one-way repeated measures ANOVA (String Type: regular correct, regular incorrect and irregular) on error rates for the test block showed a significant difference among the trial types for each task. For the multiple-triplet string types, $F(2,42) = 30.13$, $MSE = 26725$, $p < 0.001$, $\eta_p^2 = 0.589$, with the difference lying between the regular and irregular strings (pairwise comparison: regular correct vs regular incorrect $p = 0.885$, regular correct vs irregular $p < 0.001$, regular incorrect vs irregular $p < 0.001$). For the shapes task different shape types, $F(2,38) = 42.12$, $MSE = 8362$, $p < 0.001$, $\eta_p^2 = 0.689$ with each significantly different from the others (pairwise comparison: regular correct vs regular incorrect $p < 0.001$, regular correct vs irregular $p = 0.001$, regular incorrect vs irregular $p < 0.001$). The effect sizes are large for both tasks, suggesting that much of the variance in the error rates is

explained by the difference in the stimuli types. The effect size for the multiple-triplet task was smaller than for Experiment 1, but larger than Experiment 2, whereas the effect size for the shapes task was larger than for both previous experiments.

The overall error rates indicate that the irregular letter/shape in the test block was not noticed by participants some of the time, suggesting some degree of Information Reduction. In the multiple-triplet task 5 of the 22 participants (22.7%) incorrectly categorised all 12, or almost all (11), of the irregular strings, with another 7 participants (31.8%) incorrectly categorising at least half the irregular strings. There were 5 who made no errors at all to the irregular strings. In the shapes task the highest proportion of irregular incorrect categorisations was two-thirds, however 13 participants out of 20 (65%) made at least twice as many errors to the inconsistently placed as to the consistently placed differing shapes, almost double the number who did so in Experiment 1.

Table 6.1: Overall error rates in final training block and test block by stimulus type

Task	'String type'	Final training block	Test block
Multiple-triplet	Correct strings	4.5%	5.9%
	Incorrect strings	2.1%	5.6%
	Irregular strings	-	50.6%
Shapes	Matching shapes	1.3%	1%
	Differing shapes, consistent position	6.5%	5.6%
	Differing shapes, inconsistent position	-	29.4%

6.3.2 Response times

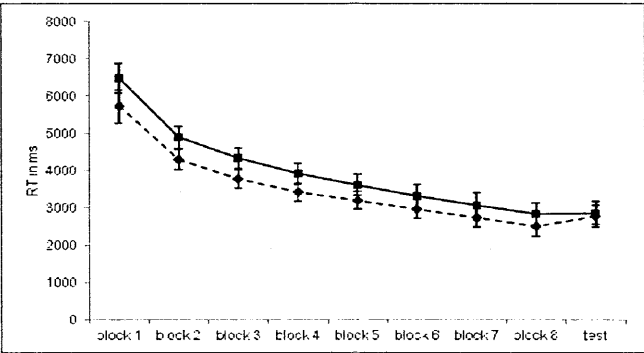
In the shapes task there was a significant correlation between overall mean RT and mean error rate in training, ($r(18) = -0.461, p = 0.041$), but not if per block mean RT and error rates were compared ($r(118) = -0.006, p = 0.948$), so it is possible that some participants used a speed-accuracy trade-off strategy, although it did not prove possible to identify any as solely using this strategy. In the multiple-triplet task the overall correlation was not significant, $r(20) = -0.364, p = 0.096$.

Figure 6.1 shows that response times decreased during each task, with RTs for correct stimuli being slower than those for incorrect. In both tasks there was some convergence of the RTs, suggesting that there was greater speeding for correct stimuli than for incorrect.

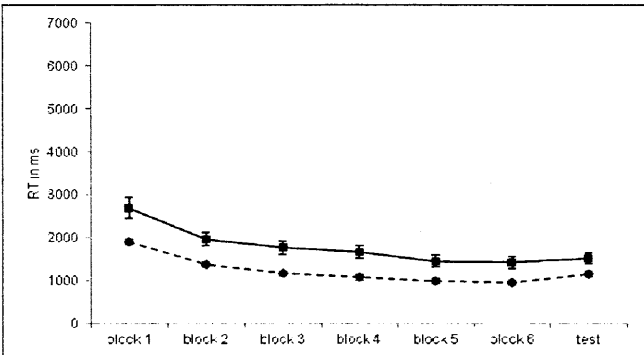
Figure 6.1: change in response times over the course of each task

Key: solid line – correct stimuli, broken line – incorrect stimuli

a) Multiple-triplet



b) Shapes



In both tasks a repeated measures ANOVA by Block showed there was a significant decrease in overall RTs during training and a significant increase in RT between the final training block and the test block (Table 6.2). The effect sizes seen for the reduction in RT over the course of training were greater than in Experiment 1, indicating that the instruction from block two onwards to be as fast as possible was effective.

Table 6.2: ANOVA results for response times, by Block

Multiple-triplet	Over training (Blocks 1-8)	$F(1,147) = 87.38$, $MSE = 101600000$, $p < 0.001$, $\eta_p^2 = 0.806$
	Final training Block – test Block	$F(1,21) = 5.95$, $MSE = 417675$, $p = 0.024$, $\eta_p^2 = 0.221$
Shapes	Over training (Blocks 1-6)	$F(5,95) = 103.85$, $MSE = 9156501$, $p < 0.001$, $\eta_p^2 = 0.845$
	Final training Block – test Block	$F(1,19) = 19.239$, $MSE = 223926$, $p < 0.001$, $\eta_p^2 = 0.503$

6.3.3 “String-length effect”

The regression slopes coefficient per participant and block were computed and subjected to a one-way repeated measures ANOVA by Block. This shows whether the RT for longer ‘strings’ decreased reliably more than that for shorter ‘strings’ and thus if a shortcut was applied to the longer ‘strings’.

For correct strings in the multiple-triplet task there was a significant reduction in the slopes during training (Blocks 1-8), $F(7,147) = 22.62$, $MSE = 2655917$, $p < 0.001$, $\eta_p^2 = 0.519$. There was a significant increase in the slopes between the final training block and the test block, $F(1,21) = 11.94$, $MSE = 184804$, $p = 0.002$, $\eta_p^2 = 0.362$. These are both large effect sizes, suggesting that some of the variance in training could be explained by an increased speeding for the longer strings and

slowing during the test block. For incorrect strings the reduction in slopes during training (Blocks 1-8) approached significance, $F(7,147) = 2.68$, $MSE = 158060$, $p = 0.053$, $\eta_p^2 = 0.113$, and there was a significant increase in slopes between the final training block and the test block, $F(1,21) = 9.3$, $MSE = 182292$, $p = 0.006$, $\eta_p^2 = 0.307$. The effect during training was medium, but in the test block was large, suggesting that there was some speeding during training but more slowing during the test block. The increase in slopes for the test block suggests that participants noticed the change in regularity and reverted to full, or fuller, checking of the stimuli.

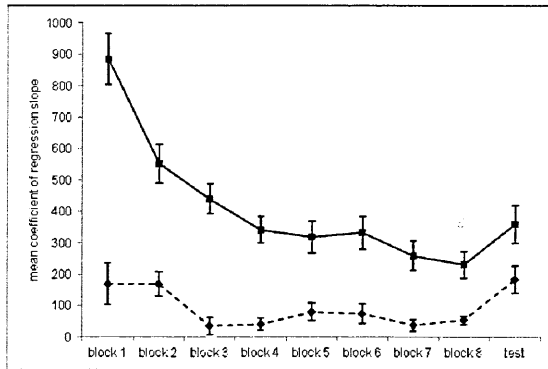
For both matching and differing shapes a significant reduction in slopes was found in training (Blocks 1-6), ($F(5,95) = 11.31$, $MSE = 194001$, $p < 0.001$, $\eta_p^2 = 0.373$ and $F(5,95) = 22.58$, $MSE = 122175$, $p < 0.001$, $\eta_p^2 = 0.543$ respectively). The effect sizes are large for both of these, suggesting that much of the variance could be explained by an increased speeding for the stimuli with more shapes. The increase in the slopes between the final training block and the test block was not significant ($F < 1$ in both cases).

Figure 6.2 shows the change in the coefficient of the regression slopes for both tasks. The mean of the regression coefficient for each block was higher for the ‘correct’ stimuli than for the ‘incorrect’. Compared to Experiment 1 there was slightly less convergence between correct and incorrect in the multiple-triplet task, although there was more than Experiment 2. There appeared to be little convergence in the shapes task.

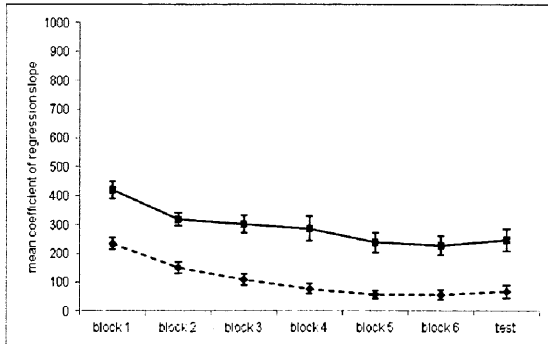
Figure 6.2: The change in coefficient of regression slopes plotted by block for the different stimuli types in the two tasks (error bars represent the standard error of the means)

Key: solid line - correct stimuli, broken line - incorrect stimuli

a) Multiple-triplet task



b) Shapes task



The correlational analysis for the mean coefficient of the regression slopes for correct strings/matching shapes over the final two training blocks with the error rate for 'irregular' stimuli in the test block was significant for both the multiple-triplet task, $r(20) = -0.658$, $p = 0.001$, and the shapes task, $r(18) = -0.671$, $p = 0.001$.

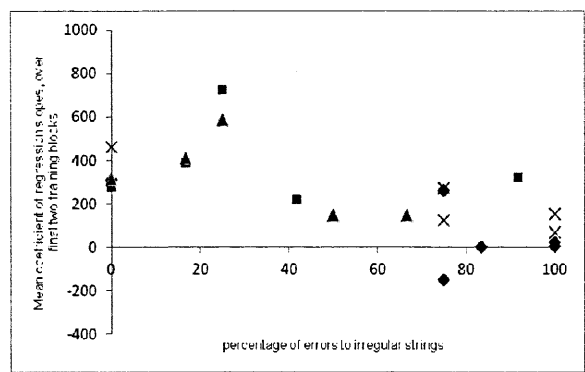
Scatterplots showing these two measures, with coding for questionnaire response, are shown in Figure 6.3.

6.3.4 Post-task questionnaires

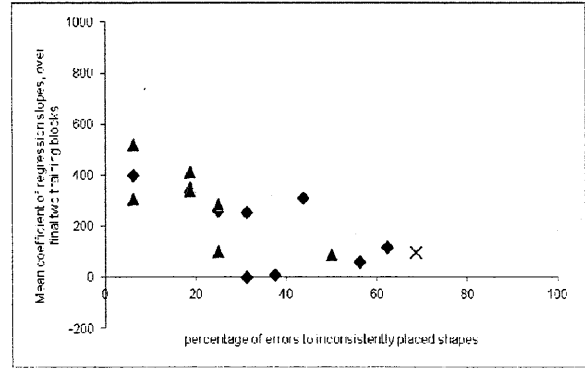
Five questionnaires for the multiple-triplet task and one for the shapes task were not returned. The responses were coded as before and are indicated in Figure 6.3.

Figure 6.3: Scatterplots showing the mean coefficient of regression slopes over the final two training blocks against the percentage of errors to the ‘irregular’ stimuli, indicating categorisation from the questionnaire

a) Multiple-triplet task



b) Shapes task



- Key
- ◆ - explicitly expressed regularity and indicated use of Information Reduction strategy
 - - aware of regularity, but continued checking irrelevant elements
 - ▲ – did not verbally express regularity
 - X – no questionnaire

In the multiple-triplet task 7 participants (32%) could be classified as reducers, with all of those who indicated that they used the strategy having an error rate above 70%. For this task there was less of a distinct split between reducers and non-reducers than the two previous experiments, which could indicate partial use of Information Reduction.

In the shapes task those with the highest number of errors had the lowest slopes, and there were more compared to previous experiments – 4 here, 2 in Experiment 2 and 1 in Experiment 1. This would suggest more participants used

Information Reduction more consistently when trying to be as fast as possible. Once again about half the participants lacked awareness of the regularity.

6.3.5 Correlation between response time and error rate

A correlation between the per block error rate and RT, for each participant separately, was carried out to examine whether it was possible to determine any strategies in use. If a participant used a speed-accuracy trade-off then it would be expected that as RTs decreased the error rate would increase, giving a negative correlation. With an Information Reduction strategy a positive correlation might be expected, with RTs and error rates declining together. The correlations are shown in Appendix 9. In the multiple-triplet task there was one participant who seemed to have used a speed-accuracy trade-off strategy, and this person showed no awareness of the regularity on their questionnaire. In this task there was also one person who had a significant positive correlation and therefore seemed to have used Information Reduction, and this was also derived from their questionnaire. One other participant with a significant correlation had not indicated any awareness of the regularity on their questionnaire. In the shapes task, there were three participants with a significant positive correlation who had indicated use of Information Reduction on their questionnaires. For all other participants the correlations were not significant and therefore revealed nothing about any strategy they might be using.

6.4 DISCUSSION

This experiment was conducted in order to investigate further the effect that altered training conditions have on the numbers of people using Information Reduction, specifically emphasising speed rather than accuracy. The attenuation of the string-length effect over training and more errors being made to 'irregular' than to 'regular' stimuli in the test block, plus the return of the string-length effect for the

multiple-triplet task, indicate that Information Reduction was occurring. It was hypothesised that more participants would adopt the strategy when requested to be as fast as possible and it does appear that Information Reduction was used more consistently in the shapes task. The string-length effect did not reappear in the test block and more participants produced an increased number of errors to inconsistently placed differing shapes than in Experiment 1, suggesting that speed stress caused Information Reduction to be used more. Additional support for this was provided by the self-reports and the per participant RT/error-rate correlation, where several had a significant positive correlation. However, once again no complete reduction was seen in the shapes task and it was not possible to determine a number of 'reducers'. Nonetheless the shapes task result is in line with the results obtained by Haider et al. (2005) that speed pressure encouraged use of Information Reduction, and with those of Touron and Hertzog (2004a) that making the scanning to memory strategy shift more beneficial increased the numbers switching.

The results for the multiple-triplet task did not support the hypothesis, with 32% identified as reducers, compared to 64% in Experiment 1. This was rather different to previously reported findings (Haider et al., 2005), on which the hypothesis was based, and the results from Touron and Hertzog (2004b). The result is particularly surprising since self-reported levels of awareness of the strategy were very similar (77% aware in Experiment 1, 71% in Experiment 3) and therefore it would be expected that all those who were aware would use Information Reduction. However, whilst all except one of those who self-identified as a reducer on the questionnaire had over 75% errors to the irregular stimuli and low slopes at the end of the task, there was not a clear division between reducers and non-reducers, unlike Experiment 1 and Experiment 2. There were many participants who exhibited low regression slopes at the end of the experiment, but with a more continuous spread of

error rates to the irregular stimuli. This is similar to the results for the shapes task in all three experiments reported so far. It is also similar to the relevant-first condition of Haider and Frensch's triplet-position-varying experiment (Haider & Frensch, 1999a), which they attribute to noticing an alphabetic inaccuracy in an irregular string part-way through the test block and then reverting to checking entire strings. They do acknowledge that some participants noticed a few of the irregularities but missed some later ones. Examination of the test blocks for the multiple-triplet task revealed that four (18%) participants incorrectly classified irregular stimuli at the start of the block and then appeared to notice that the regularity no longer held and correctly classified most of the irregular stimuli from then onwards. In the shapes task it was just two participants (10%). Since the majority showed no pattern to the irregular stimuli verified correctly or incorrectly, this may suggest that some form of partial reduction was occurring. Why people should choose not to use Information Reduction exclusively in a situation, such as speed pressure, where it might be thought more efficient, is not clear and again suggests that perhaps usage is not completely under voluntary control.

Only one participant in the multiple-triplet task could be identified as having used a speed-accuracy trade-off strategy from the per block RT/error-rate correlation. As their error-rate in each block did not exceed 10%, it would seem that not too much accuracy was abandoned. In both tasks it is possible that some participants reduced on some trials and used another strategy, such as a speed-accuracy trade-off, for others. Such inconsistent use of Information Reduction may be another way that partial reduction manifests itself, as well as the possibility mentioned in Chapter 5, that some stimuli may be fully processed and others only the relevant part. Partial reduction is contrary to Haider and Frensch's idea that Information Reduction is consciously adopted at one point in time and affects

behaviour reasonably consistently from then on. If participants were switching strategies between trials then it did not affect their overall accuracy, as similar numbers were excluded due to high error rates as in Experiment 1 and Experiment 2. Haider and Frensch (1999b) had to exclude many more in their speeded conditions. Since their experiment 1 only used instruction to optimise speed, as was done here, it is hard to see why the results are so different, although they do not specify the exact phrasing of the instructions. One explanation could be that this experiment used feedback on trials where an error was made, which may have negated the instruction to be as fast as possible and reminded the participants about accuracy. This however, would make the apparent increased use of Information Reduction in the shapes task an anomaly. It is suggested that further exploration of the effect of instructional change combined with feedback change, on both tasks, is required.

Unlike Experiment 1, there do not seem to be any non-aware users of Information Reduction in the multiple-triplet task, although it is possible that some of those who did not return the questionnaire could fall into this category, and some of the potential 'partial users' certainly do. In the shapes task there are some potential 'partial reducers' who seemed unaware of any regularity and the numbers of unaware users seem similar to Experiment 1 and 2.

It would seem from the results of Experiment 2 (Chapter 5) and this experiment that Information Reduction is more easily abandoned than increased in the multiple-triplet task, but there are indications that it can be increased in the shapes task. The results for both tasks would seem to rule out the theories of automaticity as a sole explanation, since these would not predict a variation in the amount of Information Reduction seen, whether more or less. Both Instance theory (Logan, 1988) and Production rules (Anderson, 1987) assert that performance

improvements are data-driven and an inevitable result of practice. The same number of instances were seen as in Experiment 1 and the same processes were required to respond to the stimuli, with the same amount of practice. It could be speculated that the instruction to work quickly interfered with formation and compilation of productions, and this could account for the decrease in the number of reducers seen in the multiple-triplet task, but not the apparent increase in reduction in the shapes task. The Component Power Law model (Rickard, 1997) does not fully specify the mechanism for strategy selection and is able to accommodate subjective influences, such as an emphasis on being fast (Touren & Hertzog, 2004b). However, one would assume that the instruction would have the same effect in both tasks, so automaticity does not seem to be an adequate explanation for any of the results so far.

Overall, the results from all three experiments reported so far suggest that there is variability in the usage of Information Reduction both between tasks and training conditions. Although the fact that not all participants use Information Reduction leads to the conclusion that it is not an inevitable consequence of task structure, supporting Haider and Frensch's theory that it is consciously applied, it may be more sensitive to task and training conditions than previously reported and not as simple or as robust as they have suggested. There is also a question about whether it is possible to use Information Reduction and have no awareness of doing so. The next experiment investigated the consciousness aspect in an alternative manner by encouraging the participants to engage in explicit hypothesis testing about the stimuli.

Chapter 7 EXPERIMENT 4

EXPLICIT INSTRUCTION TO FIND SHORTCUT

7.1 INTRODUCTION

The experiments described in previous chapters have demonstrated that participants often become aware of the regularity in the stimuli and make use of it, applying the Information Reduction strategy to improve their performance. However, a number appear to use Information Reduction without apparently being aware of so doing – or at least, they are unable to verbally express the regularity, and even after prompting show no awareness of having changed their processing. This experiment sought to further investigate participants' awareness by informing participants that it was possible to carry out the task more quickly by using a shortcut, but without informing them of its nature.

There have been a variety of experiments in the implicit learning literature which have compared the effect of explicit instruction with no instruction about a regularity. For instance, Curran and Keele (1993) carried out an experiment whereby one-third of participants, the intentional learning group, were explicitly informed beforehand of the 6-item repeating sequence used in the serial reaction time task and the remaining two-thirds, the incidental learning group, had no such instruction. Following a 6-block learning phase the participants were given a questionnaire which asked if they thought there was a pattern or if the sequence was random, and this was used to divide the incidental group into those who were 'more aware' (19/30 or 63% of the incidental group) and those who were 'less aware' (11/30 or 37% of the incidental group). Two-thirds of the 'less aware' reported the sequence to be random. Results showed that whilst learning of the sequence occurred in all groups, they all differed significantly in the amount of learning shown, as measured by an RT

difference between the sequence blocks and a random block. The 'less aware' showed the least learning and the explicit group showed the most learning. Subsequently all groups received four more blocks, three random and one consisting of the previously presented sequence, under dual-task conditions. There was no statistical difference between the groups in the amount of sequence knowledge shown. This was taken to suggest that there are two separate learning mechanisms and that the conscious knowledge acquired by the intentional and more aware groups could not be transferred to the nonattentional learning system, when the dual-task prevented the attentional system from implementing its knowledge of the sequence. No explanation was offered as to how or why some participants in the incidental learning group came to be aware of the sequence, where others did not, but it is interesting to note that the percentages of 'more aware' as opposed to 'less aware' are similar to those found for the multiple-triplet task in Experiment 1 reported in Chapter 4.

Willingham and Goedert-Eschmann (1999) carried out a serial reaction time experiment where one group of participants were explicitly shown the 12-unit repeating sequence during training and told to learn it, and another group of participants were simply told to respond as quickly as possible. Both groups showed a significant improvement in RT over the course of the experiment. For half of each group, the final transfer block contained the sequence used in training, amongst some random trials, and for the other half the transfer block was essentially a series of random trials. Both explicit and implicit groups were able to transfer the sequence, and respond more quickly to it than the random trials, if it appeared in the transfer block, although the explicit group did better in a subsequent free recall test. The results were taken to mean that implicit and explicit learning can occur in parallel and are mediated by two separate mechanisms, with implicit learning being

based on regularly-repeated motor behaviour. Although there was some explicit knowledge of the sequence shown by the implicit learning group, again no explanation was offered as to how this knowledge became explicit, nor was it reported how many were able to express any explicit knowledge.

Some past research using the Alphabet Verification task has informed participants beforehand of what the strategy is (Gaschler & Frensch, 2009; Haider & Frensch, 1996). Haider and Frensch (Experiment 1, 1996) had three conditions: 'Informed', 'Informed + ignore' and 'Not informed', where the participants were either told that errors could occur only within the initial 'letter-digit-letter' triplet, or were additionally instructed to try to ignore any letters following, or were told to evaluate the whole string as alphabetic inaccuracies could occur anywhere. Results showed that there was no 'string-length effect' for correct strings in the informed conditions suggesting that with explicit instruction, participants can and do process simply the triplet. Gaschler and Frensch (Experiment 1, 2009) informed participants that it was possible to ignore the trailing letters for some of the strings. Their results suggest that participants came to realise that this held true for all the strings in the training phase. However they did not report results for correct and incorrect strings separately, so it is not clear if there was less attenuation of the string-length effect for correct strings and this is masked by the aggregation of the data. Nonetheless, it seems that explicit instruction of the regularity leads very quickly to Information Reduction occurring but it does also occur when no instruction about the regularity is given.

As an alternative to giving participants explicit instructions about the task structure and the sequence or regularity, Gebauer & Mackintosh (2007) instructed their participants that there was an underlying rule, in the three implicit learning tasks

they used (artificial grammar, sequential learning and process control), and asked the participants to do their best to discover this rule. An example of the instructions was:

“Letters are presented on the computer screen. Your task is to press as fast as you can the corresponding button on the keyboard without making errors. Please try to increase your speed of responding from one block to the next, but without making any more incorrect responses. There is a single fixed sequence underlying the task. Throughout the task the same sequence is repeated. Please try to discover the sequence. It is not easy to discover the sequence but please try hard to do so. Even if you do not discover the complete sequence, you can at least find out about parts of the sequence. The more you find out about the sequence, the faster you will become and the fewer errors you will make.”

(Gebauer & Mackintosh, 2007, p40)

Although the purpose of the experiment was to investigate whether there was any correlation between implicit learning and intelligence, some results of the instructional manipulation were reported. For artificial grammar learning explicit instruction reduced performance compared to implicit instruction, whereas for sequential learning performance improved. There was no difference between instruction type for process control. Gebauer and Mackintosh suggest that these differences arose because under explicit instruction to discover the underlying rule participants were relying on explicit memory for the artificial grammar task, but were using reasoning and transfer of acquired problem-solving strategies for the sequential learning and process control tasks. However they considered that none of these cognitive processes were employed under implicit instruction. No data was presented to show how many participants did actually discover the rule in any of the tasks, nor did they investigate any verbally reportable knowledge acquired in the implicit learning groups. However, the experiment does suggest that, for some tasks at least,

participants are able to successfully engage in hypothesis testing to improve performance, when instructed to find a rule. Since the participants were, for the most part, teenagers at school it may be that this result would not be replicated with adults.

Information Reduction has been proposed as a top-down consciously implemented strategy, which follows implicit learning of a regularity. Some empirical evidence has been presented to support this idea. Haider and Frensch (1996) and Haider et al. (2005) demonstrated that, having learned the strategy on one set of stimuli, it could be transferred to a novel set of similar stimuli. The two sets of stimuli started with different letters in the alphabet: D-H and I-M with the triplet at the start of the string for Haider and Frensch (1996) and E-L and M-T with the triplet being located at the end of the string for Haider et al. (2005). The later experiment used a drop in latency of > 1 s between blocks on the first set of stimuli as a measure of a strategy switch. Using this method approximately half the participants were classed as reducers and they were found to return to the performance level of the first set of stimuli within two blocks of transfer, whereas those classed as non-reducers did not. The transfer phase only had two blocks and there was no block in which irregular strings occurred. A post-testing questionnaire asked participants to describe the characteristics of the strings and any strategies used to process them, both at the beginning and the end of the experiment. This yielded results suggesting that most of those who had the abrupt drop in latency were able to verbalise the Information Reduction strategy. However, there were a few who did not, or could not, describe the regularity or any strategy used. This could mean that the method used to determine a strategy switch was not 100% reliable, or it could mean that some people lack awareness of their strategy use or are unable to verbalise it. Gaschler and Frensch (2007) varied the frequency with which strings were

presented and found that the string-length effect attenuated at the same rate for both frequently-presented and infrequently-presented strings, suggesting that Information Reduction was applied regardless of how often a stimulus was seen. However, this experiment did not assess explicit knowledge. These item-general findings would therefore seem to rule out Information Reduction being a result of instance learning and may suggest that it is only used when a participant becomes aware of the regularity.

A number of theories have been proposed about the relationship between explicit and implicit learning but for the most part these offer no coherent explanation as to why or how some participants show awareness of any incidentally learned sequence or regularity whilst others do not. It has been noted in the implicit sequence learning literature that whilst many participants are unable to verbally report what has been learned, there are always some who can (Haider & Frensch, 2009). Depending on the experimental conditions, this can vary from 10% to 70% (Frensch et al., 2003). There is evidence, such as that from Curran and Keele, and Willingham and Goedert-Eschmann, outlined above, that implicit and explicit processes are separate learning systems, although there may be some brain regions common to both. Generally it is considered that the two types of learning can occur in parallel but it is not clear whether they occur independently or whether there can be transfer of knowledge from one system to the other, and whether this is uni- or bidirectional. Other theories suggest that implicit learning occurs first and is transformed into explicit verbal knowledge. One idea is that performance gains can only occur when the knowledge becomes explicit, which does appear to be at odds with experimental results indicating that some people do not apparently possess explicit knowledge. However, it is notoriously difficult to assess whether a participant is aware or not of the regularities they have learned (Frensch & R nger,

2003). Verbal reports do not satisfy the information criterion (what is tested is not the thing which led to the learning) or the sensitivity criterion (the test is less sensitive than those which demonstrated that learning has occurred). Nonetheless R nger and Frensch (2010) argue that verbal report is the most sensitive and valid measure of conscious awareness of an implicitly learned sequence. Alternative methods to test awareness include using a recognition memory probe and asking the participants after individual trials whether they had used a particular strategy or not (Touron & Hertzog, 2004a; Touron & Hertzog, 2004b).

One theory about how implicit learning becomes explicit knowledge that can be verbally expressed suggests that it is due to the strength of the representation (Cleeremans and Jim nez, 2002). As practice proceeds then the representation becomes more stable, strong and distinct in quality. At some point it crosses a threshold and is available to consciousness and can guide intentional behaviour, although behaviour may have adapted to an environmental regularity before this point is reached. This theory would explain differences between participants in verbal knowledge by differences in amount of practice required to reach the threshold.

Another suggestion as to how an implicitly or incidentally learned regularity can enter conscious awareness, which builds on previous theoretical ideas and is based on empirical data from the Alphabet Verification task and from the Number Reduction Task, is the Unexpected-Event hypothesis (Frensch et al., 2003). Support for this, over the representational-strength hypothesis, was provided from an SRT-task which manipulated the amount of practice received and found that this did not significantly affect the number of participants with verbalisable knowledge of the sequence (Schwager et al., 2012). The Unexpected-Event hypothesis suggests that the implicit learning changes behaviour and it is the conflict between what is

expected and what is performed, such as a rapid or premature response before a stimulus has been fully processed, that leads to an examination and attribution of causes for this occurrence. This can subsequently manifest itself in verbal report. The Unexpected-Event hypothesis is able to explain the fact that some do not become aware of the regularity either by the fact that no conflict between performance and expectation of performance is noticed or that no attributable cause is found. Haider and Frensch also note that participants who can report a sequence have shown a large and abrupt latency drop during the course of the experiment, and link this to the point at which the knowledge moves into declarative memory – in other words that performance does not consistently improve until after knowledge about a regularity that can be exploited becomes available to consciousness. It would therefore seem worthwhile to investigate further whether everyone who appears to use the Information Reduction strategy is able to report that they do so.

Experiments which compare groups given either explicit instruction about the nature of any sequence or regularity or no instruction provide little information about differences within the incidental learning group, and, in particular, about those who are able to give a verbal report compared to those who cannot (Frensch et al., 2003). Therefore a methodology similar to that employed by Gebauer and Mackintosh was adopted for this experiment, with the participants instructed to try and discover a way to improve their performance. In addition they were asked to indicate when they had done so and then were instructed to use the strategy found for two more blocks – a final block of training and an unannounced test block containing irregular stimuli.

In line with the results from Experiment 1 and those of Curran and Keele (1993) it was predicted that in the multiple-triplet task about two-thirds of participants would discover and be able to indicate the Information Reduction

strategy. As it has proved impossible to determine usage of Information Reduction with the shapes task no prediction about numbers for this was made. Additionally, from the Unexpected-Event hypothesis, it was predicted that everyone who had a high rate of errors to irregular stimuli in the test block would have indicated that they had discovered the Information Reduction strategy.

7.2 METHOD

7.2.1 Participants

There were 67 participants, all Open University students studying psychology, none of whom had participated in other experiments. There were 31 participants (5 male) in the multiple-triplet task and 36 (10 male) in the shapes task. All participants carried out one task only. Their ages ranged from 21 – 60, mean age 42.

7.2.2 Materials

The materials for the multiple-triplet and shapes tasks were as in previous experiments.

7.2.3 Procedure

The procedure until the end of the practice trials was as previous experiments. After being instructed to “pay close attention to the [stimuli] as errors can occur anywhere” as in all previous experiments, the participants were then instructed:

When carrying out this experiment, some people find a shortcut which helps them to respond more quickly.

If you feel that you have found a shortcut, please press Y on your keyboard, instead of M or Z, and you will be asked a question about what you have discovered, before having two more blocks to complete.

Please do not worry if you do not find a shortcut.

There will be a maximum of [number] blocks to complete.

The first training block was presented and participants could indicate at any time during this block or the following six (multiple-triplet task) or four (shapes task) blocks if they had found a shortcut. If they did so then they were presented with the following screen:

Multiple-triplet task: *Please select the option which you think is the shortcut*

- 1. A string is correct if you can make a word e.g. B(4)G = BAG*
- 2. I only need to process the first letter-digit-letter*
- 3. The longer strings are always correct*
- 4. Every alternate one is correct*
- 5. Other*
- 6. I couldn't work out a shortcut*

Shapes task: *Please select the option which you think is the shortcut*

- 1. The boxes match when there are more shapes in them*
- 2. I only need to look at the shape on the middle right*
- 3. It is correct if there is a triangle in the box*
- 4. Every alternate one is correct*
- 5. Other*
- 6. I couldn't work out a shortcut*

After indicating which option applied to them, the participants were informed:

You will now have two more blocks to complete.

Please use the shortcut you have identified when deciding on your response.

The final two blocks consisted of one more training block and the unannounced test block, so that all experienced one full training block where they could apply their shortcut, before the test block. Participants who did not indicate they had found a shortcut received the full number of training blocks – eight for the multiple-triplet task and six for the shapes task. This was followed by the unannounced test block and they did not see the screen of questions about the shortcut.

Participants also received a post-testing questionnaire investigating functional and dysfunctional impulsivity, trust in memory and distractibility, which is fully described and results presented in chapter 8.

7.2.4 Design

The within-participants independent variables were ‘string length’ and type of ‘string’: regular correct, regular incorrect or irregular. For the multiple-triplet task the string length was one, two or three triplets and for the shapes task it was 3-6 shapes.

There were 60 strings per block in the multiple-triplet task, with a maximum of 8 training blocks, giving up to 480 trials during training. There were 80 shape stimuli per block in the shape matching task, with a maximum of 6 training blocks, giving up to 480 training trials. In each task half of the training strings in each block were correct and half were incorrect. Each task had one practice block of 10 stimuli at the beginning and one test block after the training blocks. The test block had some regular incorrect stimuli replaced with irregular ones – 12 for the multiple-triplet task and 16 for the shapes task.

The dependent variables were response time (RT) to each stimulus and number of stimuli incorrectly responded to in the first and last training blocks and the test block.

7.3 RESULTS

7.3.1 Accuracy

The analysis excluded participants with errors in training of 10% or greater for each trial block. In the multiple-triplet task two were excluded, leaving 29 participants' data, and in the shapes task seven participants were excluded, leaving 29 participants' data.

Table 7.1 shows that similar numbers of errors were made to the 'regular' strings and shapes in the final training block and the test block but more errors were made to the irregular strings or inconsistently placed shapes. Error rates to the irregular stimuli ranged from 0% to 100% for both tasks.

In the multiple-triplet task 5 of the 29 participants incorrectly categorised all 12 of the irregular strings, with another 9 incorrectly categorising 10 or 11 of the irregular strings. Thus 48.3% of the participants made a high number of incorrect categorisations. The other 15 participants had 3 or fewer irregular strings incorrectly categorised. In the shapes task one person incorrectly categorised all 16 irregular stimuli and one other incorrectly categorised 15. Nine other participants incorrectly categorised at least half of the irregular stimuli. Overall, 17 participants (58.6%) made at least twice as many errors to the inconsistently placed as to the consistently placed differing shapes.

A one-way repeated measures ANOVA (String Type: regular correct, regular incorrect and irregular) on error rates for the test block showed a significant difference among the trial types for each task. For the multiple-triplet task string types, $F(2,56) = 25.3$, $MSE = 34.262$, $p < .001$, $\eta_p^2 = .475$, with the difference lying between the regular and irregular strings (pairwise comparison: regular correct vs regular incorrect $p = 0.773$, regular correct vs irregular $p < .001$, regular incorrect vs

irregular $p < .001$). For the shapes task different shape types, $F(2,56) = 39.03$, $MSE = 17,718$, $p < .001$, $\eta_p^2 = .582$ with each significantly different from the others (pairwise comparison: regular correct vs regular incorrect $p < .001$, regular correct vs irregular $p < .001$, regular incorrect vs irregular $p < .001$). The effect sizes are large, suggesting that much of the variance in the error rates is explained by the difference in the stimuli types. The size of the effect for the multiple-triplet task is smaller than Experiment 1, whereas it is larger for the shapes task.

Table 7.1: Overall error rates in final training block and test block by stimulus type

		Final training block	Test block
Multiple-triplet task	correct	7.5%	5.3%
	regular incorrect	3.4%	4.8%
	irregular	-	48.3%
Shapes task	matching	0.8%	0.5%
	differing	7.9%	9.9%
	irregular	-	36.4%

7.3.2 Indication of shortcut

In the multiple-triplet task fifteen participants indicated they had found a shortcut, with six of those choosing the Information Reduction option from the list. Thus 21% of participants found the Information Reduction strategy, 31% thought they had a different performance-enhancing strategy and 48% did not indicate a shortcut and carried out the entire experiment. The number of trials completed, before indicating, ranged from 23-148 for those choosing the Information Reduction option and 20-301 for those choosing any of the alternative options.

In the shapes task eighteen participants indicated they had found a shortcut, with ten of those choosing the Information Reduction option from the list. Thus

34.5% of participants found the Information Reduction strategy, 27.6% thought they had a different performance-enhancing strategy and 37.9% did not indicate a shortcut and carried out the entire experiment. The number of trials completed, before indicating, ranged from 9-375 for those choosing the Information Reduction option and 26-280 for those choosing any of the alternative options.

In the shapes task the range of trials experienced before indicating a shortcut had been found was wider than for the multiple-triplet task. In particular some participants waited longer before indicating. There were more who selected the Information Reduction option, but this is accounted for by there being fewer who did not notice a strategy at all. It is striking that one-third of participants in both tasks thought they had found a shortcut, but selected the 'other' option. This does not seem to be due to responding more rapidly, as the range of trials experienced was similar to those who selected the Information Reduction option. Only two people, both in the multiple-triplet task, selected a different option to either 2 (Information Reduction) or 5 (Other) and only one person stated after the experiment that despite thinking he had found a shortcut, it wasn't until he saw the list that he realised what it actually was. This suggests that even reading the 'correct' shortcut in the list of options did not prompt participants to re-evaluate their strategy.

7.3.3 Response times

There was no significant correlation between overall mean RT and mean error rate across the first and final training blocks for the multiple-triplet task, $r(56) = .007$, $p = .956$; however, there was a significant correlation overall for the shapes task, $r(56) = .27$, $p = .04$. The correlation was not significant in the first block, $r(27) = -.128$, $p = .508$, but was significant in the final block, $r(27) = .441$, $p = .017$,

suggesting there may have been some speed-accuracy trade-off in this block for this task.

Since the number of blocks for each participant varied, changes in RT were only tested, by one-way ANOVA, between the first training block and the final training block, and the final training block and the test block. Table 7.2 gives the mean RTs for these blocks in both tasks and shows that the RTs decreased over the course of the experiment, although they increased in the test block for the shapes task.

Table 7.2: mean RTs in ms for blocks used in the ANOVA

	First training block	Final training block	Test block
Multiple-triplet task	5187	3527	3423
Shapes task	2268	1352	1643

In the multiple-triplet task there was a significant decrease in RTs between block 1 and the final training block, $F(1,28) = 73.15$, $MSE = 39,982,067$, $p < .001$, $\eta_p^2 = .723$, and a non-significant decrease between the final training block and the test block, $F < 1$. This indicates that participants got faster during the training they carried out, even though they completed different numbers of trials, and that they did not slow down in the test block. Slowing in the test block would indicate that they resorted to fuller checking of the strings.

In the shapes task, there was a significant decrease in RTs between block 1 and the final training block, $F(1,28) = 51.2$, $MSE = 12,146,415$, $p < .001$, $\eta_p^2 = .646$, and a significant increase between the final training block and the test block, $F(1,28) = 5.63$, $MSE = 1,223,540$, $p = .025$, $\eta_p^2 = .167$. Participants got faster during training,

but slowed during the test block, probably indicating that fuller checking of the stimuli took place in the test block.

7.3.4 “String-length effect”

For correct strings in the multiple-triplet task there was a significant reduction in the slopes from first to final training block, $F(1,28) = 13.89$, $MSE = 698,771$, $p = .001$, $\eta_p^2 = .331$, but no significant increase from the final training block to the test block, $F < 1$. For incorrect strings there was a non-significant reduction in slopes during training (first-final training block), $F(1,28) = 1.94$, $MSE = 279,713$, $p = .174$, $\eta_p^2 = .065$, but a significant increase in slopes from the final training block to the test block, $F(1,28) = 12.53$, $MSE = 593.108$, $p = .001$, $\eta_p^2 = .309$. The effect size was large for correct strings, although smaller than for Experiment 1, and medium for incorrect strings. This is consistent with the use of Information Reduction by many of the participants, and only some of them reverting to fuller checking in the test block.

For matching shapes a significant reduction in slopes was found from first to final training block, $F(1,28) = 20.11$, $MSE = 692,531$, $p < .001$, $\eta_p^2 = .418$. For differing shapes there was also a significant reduction in slopes during training (first-final training blocks), $F(1,28) = 8.1$, $MSE = 251,835$, $p = .008$, $\eta_p^2 = .224$. These are large effect sizes, suggesting that some of the variance could be explained by an increased speeding for stimuli containing more shapes, and they are of similar order to Experiment 1. For matching shapes there was a significant increase in the slopes between the final training block and the test block, $F(1,28) = 5.43$, $MSE = 138,380$, $p = .027$, $\eta_p^2 = .163$, but for differing shapes there was a non-significant increase in the slopes between the final training block and the test block, $F(1,28) = 2.06$, $MSE =$

It can be seen that there are ten reducers in the multiple-triplet task (34%), with another four possibly using it (high error rate but their slopes are higher than would be expected if full reduction was occurring), and two reducers in the shapes task. Half the reducers in the multiple-triplet task did not apparently notice the shortcut. Those who chose the ‘other’ option from the list mostly had high slopes and low error rates, suggesting that whatever strategy they had found did not make them faster at the longer ‘strings’ and enabled them to spot all or most of the irregular stimuli in the test block.

Comparisons of the percentages of participants who indicated that they were aware of the Information Reduction strategy with those in Experiment 1 whose questionnaire responses were categorised as aware (whether or not they used Information Reduction) are given in table 7.3.

Table 7.3: comparison of percentage of participants aware of Information Reduction strategy with Experiment 1: control

	Multiple-triplet task	Shapes task
Experiment 1: control	73%	41%
Experiment 4: explicit instruction	21%	35%

7.4 DISCUSSION

The most noticeable result from this experiment, which was not predicted, is that one-third of participants in both tasks erroneously thought they had found a shortcut. Consequently the hypothesis that, in the multiple-triplet task, two-thirds of participants would discover and be able to indicate the Information Reduction strategy was not supported. Although the set-up of the experiment did not allow for descriptions of these apparent strategies to be garnered, it is clear from the fact that for the most part in both tasks these participants had steep regression slopes in the final training block that the ‘shortcuts’ employed were not effective in allowing

greater speeding for longer strings. It can also be concluded that these participants were not prompted by reading the 'correct' shortcut in the list of options to realise what it was and that they maintained their own processing. One participant indicated post-hoc that reading the list of options revealed what the 'true' strategy was and that processing was changed accordingly for the final two blocks. This participant was counted as having discovered the Information Reduction strategy. All the participants who indicated another strategy did show some speeding at all 'string lengths', but this could have been solely the speeding due to practice. It is possible that these participants would have discovered the Information Reduction strategy if they had received more practice, but the range of trials experienced by them was the same as the participants who did discover the strategy. This suggests that the amount of practice may not be a factor. One possibility is that some, at least, did not receive sufficient practice to enable them to notice the 'true' regularity and a future experiment could give all participants one full block of training before allowing them to indicate they had found a shortcut. Haider et al. (2005) had an experimental procedure which tracked whether there was an abrupt reduction in RTs between blocks, rather than the cessation of practice being participant-led. This may ensure that only those who find the Information Reduction strategy and can process all 'strings' equally quickly exit from practice early, although participants who discover it in the first block may not be picked up. A future experiment could use this methodology but also test participants' knowledge of any strategy they were using, to see if more are aware of Information Reduction when they are not explicitly trying to discover a shortcut.

One aspect of the results that is apparent, from table 7.3, is that the results for the multiple-triplet task and shapes task differ from each other when compared to the control experiment (Experiment 1). Whilst for the shapes task the percentages of

Information Reduction aware participants was similar in both experiments, the proportions differ markedly for the multiple-triplet task, with far fewer showing any knowledge of the strategy. This could suggest that it is more important in the multiple-triplet experiment to have more practice. This may be related to the additional processing required in the calculation, adding to working memory load, and thus preventing the hypothesis-testing needed to determine the most efficient strategy.

The representation-strengthening theory of how implicit learning becomes explicit knowledge (Cleeremans and Jiménez, 2002) would suggest that amount of practice is crucial to being able to indicate awareness of the regularity, although the amount of practice needed to reach the threshold may vary between participants. It does not easily account for those who mistook the regularity and erroneously thought they had discovered the shortcut. However, it could be speculated that inducing hypothesis-testing meant that this processing masked the implicit learning occurring, thus preventing it from gaining sufficient strength to become available to consciousness.

Nevertheless, the finding that one-third of participants did not choose the Information Reduction option from the list does suggest that even when deliberate hypothesis-testing is induced, some participants do not notice the regularity built-in to the task. Gebauer and Mackintosh (2007) suggested that the differential results they obtained by type of implicit-learning task were due to different cognitive processes utilised to discover the rule. Whilst all participants here carried out the same task, it could be speculated that whether they primarily used working memory or reasoning processes to try and elucidate the shortcut varied, perhaps due to individual differences in intelligence, personality, emotional state or other factors. Future experiments might investigate what kinds of shortcut these participants

thought they had discovered: were they similar or was each unique to the participant? For instance, the post-testing questionnaires suggested that a few participants believed there was a regularity underlying the presentation order of the stimuli, although this was in fact random. A future experiment could also explore if it is possible to identify any consistent individual differences between those who found the regularity which enables Information Reduction and those who developed another strategy. The measures tested here (distractibility, impulsivity and trust in memory; see chapter 8) did not distinguish between the three types of participant: aware Information Reduction users; non-aware users; and other shortcut.

This finding of approximately one-third aware users, one-third non-aware users and one-third incorrect hypothesisers does reflect results found by Lambert and Roser (2001) in a spatial cueing experiment. They used a subtle difference in colour between non-centrally located cues to indicate a relationship between cue and target position on a high percentage of trials and a post-testing questionnaire to test awareness. They found 23% were explicitly aware of the relationship and had faster RTs to valid than invalid test trials, 40% who showed no awareness of the relationship but had faster RTs to valid test trials and 37% who they categorised as semi-aware but who did not exhibit faster RTs. It was suggested that this latter group were aware there was some sort of relationship between cue and target but had not correctly identified what it was and were forming and testing incorrect hypotheses about the relationship. However, they did not vary the amount of practice so it is not clear if increasing it would mean more participants finding the correct hypothesis.

Those who picked the Information Reduction option from the list had, in general, low slopes in the final training block and a high error rate to irregular 'strings' in the test block. They could thus be categorised as reducers from the scatterplots. As the participants who indicated discovery of a shortcut were asked to

use it for the final two blocks, this would be expected. In the multiple-triplet task all except one of those who indicated Information Reduction are seen to have reduced by the measures used. This provides converging evidence for these measures being indicative of Information Reduction. In the shapes task most who selected the Information Reduction option are further towards the reducer side of the plot than seen in previous experiments, but a couple still managed to spot most of the irregular stimuli. This experiment confirms that some people in the shapes task can know what the regularity is, and apply the shortcut, but are still able to spot some or most of the irregular stimuli and reasons for this need to be explored. Nonetheless, results here demonstrate that it is possible to get 'full' reduction in the shapes task. The results can also be taken as confirmation that what has been seen in the shapes task in previous experiments, reported in chapters 4-6, is Information Reduction, albeit perhaps 'partial'. Again there may be individual differences between participants, possibly in attentional processes, which mean some are better at applying the shortcut or focussing solely on the relevant area of the stimulus and this could be explored in future experiments.

The Unexpected-Event hypothesis predicted that everyone who had a high rate of errors to irregular stimuli in the test block would have indicated that they had discovered the Information Reduction strategy but this is not the case. In the multiple-triplet task half of those whose RT data and error rate suggests use of the Information Reduction strategy never indicated that they had discovered a shortcut. In the shapes task it is harder to determine but it would appear that some of those who did not indicate discovery of a shortcut were using Information Reduction to some extent. These results suggest that some people can use the strategy without apparently being aware of it, although it cannot be ruled out that non-indicators were aware but lacked the confidence to indicate this, or did not understand the

instructions. Alongside the evidence from experiments 1-3 reported in chapters 4-6, and those of Curran and Keele (1993), where one-third of their incidental learning group showed less or no awareness of a regularity, it does seem that some performance improvement from implicit learning can occur separately from any explicit knowledge. Schwager et al. (2012) did find that there was some implicit learning and performance improvement amongst those who were categorised as non-verbalisers, despite their overall conclusion that their results supported the Unexpected-Event hypothesis. In general, the implicit learning literature suggests that some can verbally report regularities and some cannot. Overall these results are compatible with the basic premise of the Unexpected-Event hypothesis, which deals with a mechanism by which implicit knowledge may become explicit. However, the results would appear to be at odds with Haider and Frensch's idea that performance does not consistently improve until after knowledge about a regularity that can be exploited becomes available to consciousness, since some of those who showed no awareness in the multiple-triplet task had very low slopes and did not spot any of the irregular strings.

Finding that some participants appear to use the strategy despite not being able to verbalise their knowledge is compatible with the representational-strength hypothesis, since that does not require verbal knowledge for behaviour to have been affected. Therefore these results do not distinguish between the basic idea of the Unexpected-Event hypothesis or the representational-strength hypothesis. Other theoretical ideas, such as implicit learning being separate and independent from explicit learning may be supported by the results of this experiment, although these theories generally offer no explanation of why some people become explicitly aware of implicitly learned regularities. It may revolve around whether attention has been involved. Curran and Keele (1993) suggested that there can be nonattentional

learning which is associative, nonaware attentional learning and aware attentional learning. However it is not clear under what conditions these processes might operate and whether they occur differentially in individuals, although reportable knowledge may be influenced by individual differences in attention allocation and short term memory capacity (Cleeremans, 1993). Shanks suggests that implicit learning may require some attentional resource and result in some level of awareness of the relationship between the stimuli (Shanks, 2003), as well as suggesting that implicit and explicit learning may be neither functionally nor neurally separate. Common brain regions for implicit and explicit learning could explain why equal levels of performance are seen in both aware and non-aware participants, but again offer no explanation as to why some can verbally express the regularity and some apparently cannot.

It has been proposed that the implicit learning occurring in different tasks is not necessarily comparable and may involve different learning mechanisms leading to different representations (Frensch & R nger, 2003; Gebauer & Mackintosh, 2007). If this is the case then it becomes very difficult to theorise both about mechanisms of implicit learning and links between implicit and explicit learning.

Nonetheless, this experiment does clearly show that participants who discovered the Information Reduction shortcut did so after differential amounts of practice, with some needing less than one block of trials and some needing two or more blocks. The range of trials experienced was wider for the shapes task, although it is not known why this should be the case. The fact that different amounts of practice are needed supports the results obtained by Haider and Frensch (2002) where the performance discontinuities for their six participants occur at different times during the 30 practice blocks and the results of Haider et al. (2005) who monitored change in latency between consecutive blocks and ceased practice for

participants who showed an RT drop of >1 s, although they only report the average number of training blocks completed. The amount of practice required to discover Information Reduction may be due to individual differences and this is something which future experiments could investigate. It is a matter of speculation as to whether all would come to use and/or be aware of Information Reduction if given sufficient practice, but if willing participants could be found then this would be a useful avenue to explore.

The next chapter reports the results from the individual difference questionnaires employed alongside this experiment and also those used with the transfer experiment which is detailed in chapter 9.

Chapter 8 TESTING INDIVIDUAL DIFFERENCES

8.1 INTRODUCTION

It has long been known that people learn at different rates (Bryan & Harter, 1899) and it has also been shown that implicit learning is not an inevitable consequence of task presentation (Karpicke & Pisoni, 2004). These results may arise due to processing differences between people, either due directly to differences in, for example, working memory capacity, or indirectly due to factors such as personality traits impacting on cognition. Although such differences apply to groups i.e. people can be divided into those with low, medium or high working memory capacity or a particular personality trait, they are referred to as individual differences.

Individual differences may be apparent in the learning, application and modification of strategies (Sohn, Doane, & Garrison, 2006; Taatgen, 2013). For instance, Sohn et al. found that cognitive ability affected both which strategy was used and ease of transfer in the polygon discrimination task. This series of experiments, along with previous research (Haider & Frensch, 1999a) has shown that some people are aware of the regularity that can lead to Information Reduction and some are not. Both some of the aware and some of the non-aware have been noted as users of the strategy ('reducers'), and it is also noted that knowledge of the strategy does not necessarily lead to its use. This gives rise to four broad categories: aware users, aware non-users, non-aware users and non-aware non-users. Having established these groups from Experiment 1, and in subsequent experiments, the question arises as to whether there is some particular individual difference which could identify these groups. For example, variations in attentional focus, motivation and emotion regulation as a result of personality traits may affect training and

practice (Kluge, Ritzmann, Burkolter, & Sauer, 2011). There is also the question of whether it would be possible to identify those who are able to transfer from one set of stimuli to another (Haider & Frensch, 1996; Haider et al., 2005) (Chapter 9).

Individual differences in general cognitive capacities and aspects of general intelligence are thought to play a part in whether or not skill successfully transfers from one task to another (Barnett & Ceci, 2002). Consequently a variety of psychometric variables were explored alongside Experiments 4 and 5, to examine aspects of personality and processing.

Previous research examining individual differences in skill acquisition and transfer has looked at the general cognitive abilities of general reasoning, spatial visualisation, perceptual speed, spatial problem solving and verbal comprehension (Sohn et al., 2006). It was found that overall level of ability affected which strategy was adopted initially in a visual discrimination task and also whether transfer to new stimuli was successful. The different cognitive abilities were not examined separately, so it is not known if one, several, or all of the factors measured are relevant to strategy usage. Edmunds (2005), using the target search task, employed the State-Trait Anxiety Inventory (Spielberger, Gorsuch, & Lushene, 1970) and the matrix-reasoning sub-test of the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999) to examine whether reducers could be distinguished from non-reducers by either anxiety or intelligence. He analysed a variety of measures arising from the task that could potentially be indicative of whether someone is reducing: the difference between the regression coefficients for the first and last training blocks; mean errors in the final training block; errors to irregular stimuli in the test block; the difference in RT between the last training block and the test block; and the difference in RT between the final training block and the test block for the longest strings only. Using linear regression he found that neither state nor trait

anxiety nor total IQ score were predictive of the values for any of the variables tested and that all the measures gave similar results. When the IQ score was broken down into spatial and pattern-matching components, the pattern-matching was found to be predictive of the errors made to irregular stimuli in the test block, suggesting that those who are good at focussing on detail are less likely to be reducers. This trait could be referred to as thoroughness, perfectionism or perhaps conscientiousness.

For this study a number of potential individual difference areas were considered, with the provisos that testing would not take long, since the main task already occupied up to an hour of the participant's time, and that testing could be carried out remotely. Auditory digit span has been linked to individual differences in implicit learning (Karpicke & Pisoni, 2004). Working memory capacity, and its role in attentional control, has been suggested as possibly involved in inattentive blindness (Seegmiller et al., 2011). However, testing working memory span or auditory digit span remotely was ruled out, as was using Raven's Progressive Matrices to measure fluid intelligence, since this would need to be purchased, but factors for which questionnaires have been developed were possible. Personality differences are known to be associated with differences in cognitive processing, including probability learning (Dickman, 1990) and learning a regularity could be compared to this type of learning. Personality is often subdivided into the traits of agreeableness, conscientiousness, extraversion, neuroticism and openness to experience (McCrae & Costa, 1987), although there are other sub-factors which can be considered, such as impulsivity and distractibility. In addition, it was noted in a number of the post-testing questionnaires returned for the multiple-triplet task in Experiments 1-3, that some participants used a memory strategy, whereas others said they did not trust

their memories and consequently counted through the alphabet each time. Therefore another potential area to explore was trust in memory.

This was an exploratory study and no hypotheses were made about potential factors which may be implicated in usage of Information Reduction.

8.2 THE MEASURES USED

Initially some fairly specific individual differences were investigated. These were impulsivity, using the Dickman functional and dysfunctional impulsivity scales (Dickman, 1990); distractibility, using the Cognitive Failures Questionnaire (Broadbent et al., 1982); and trust in memory, using the Squire Subjective Memory Questionnaire (Squire et al., 1979). Subsequently, a more general test of personality, using the 10-item scales of the International Personality Item Pool (Goldberg et al., 2006; <http://ipip.ori.org/>) and a test of ‘cognitive miserliness’, using the 10-item Cognitive Reflection Test (Frederick, 2005; personal communication, 2014) were administered.

8.2.1 Impulsivity

Impulsivity is the tendency to deliberate less than others of equal ability and may include risk taking behaviour. It has been suggested as the component of extraversion which is most closely associated with observed individual differences in signal detection, vigilance and retrieval from short- and long-term memory (Dickman, 1990), possibly because accuracy is sacrificed in favour of speed. Impulsivity is also related to a deficit in the ability to inhibit actions (Logan, Schachar, & Tannock, 1997). Therefore it may potentially be a factor in whether someone is a reducer or not. However, impulsivity is not linked to whether or not participants learn the good decks in the Iowa gambling task (Glicksohn et al., 2007), so it would seem that it does not affect implicit learning.

Dickman presented evidence that impulsivity itself consists of two distinct facets, functional and dysfunctional, which can be distinguished by self-report. This was supported by the cross-scale analysis carried out by Miller, Joseph and Tudway (2004). Whilst dysfunctional impulsivity always gives rise to negative consequences such as a high error rate, functional impulsivity may be an optimal response in some situations, because it leads to better overall performance. That is, increased speed allows more items to be processed, even if there are errors for some of them. Functional impulsivity may be useful in situations where not all information is relevant, as in Information Reduction tasks. Functional impulsivity has been related to extraversion and dysfunctional impulsivity to conscientiousness on the five-trait model of Costa and McCrae. Functional impulsivity also correlates with the venturesomeness component of Eysenck (Miller et al., 2004), whereas dysfunctional impulsivity correlates with impulsiveness on that scale. These factors can be designated as trait impulsivity (Leshem & Glicksohn, 2007). These differing correlations suggest that the two facets of impulsivity should be assessed separately. Given the relationship to other personality factors, as well as the possibility that impulsivity may lead to less of a stimulus being processed, it seemed worthy of investigation in relation to Information Reduction usage.

Examples of questions used are:

For functional impulsivity – People have admired me because I can think
quickly

For dysfunctional impulsivity – I often get into trouble because I don't think
before I act

Participants respond with a true/false answer. The full scales can be found in Appendix 2.

8.2.2 Distractibility/Cognitive Failures

Distractibility is an inability to ignore task-irrelevant stimuli (Forster & Lavie, 2007), and thus would appear to be relevant to whether someone is a reducer or non-reducer. Distractibility can be assessed using the Cognitive Failures Questionnaire (CFQ) (Broadbent et al., 1982; Forster & Lavie, 2007). It has been shown that individual differences in cognitive abilities such as attention control and working, retrospective and prospective memory can predict these type of everyday failures (Unsworth, Brewer, & Spillers, 2012), with cognitive failures being negatively related to vigilance and positively related to attentional problems (Wallace & Vodanovich, 2003). The CFQ is a well-validated scale, being internally consistent and having test-retest reliability (Wallace & Vodanovich, 2003). Forster and Lavie found that those scoring more highly on distractibility, as measured by the CFQ, experienced greater distractor interference in perceptual load tasks. Therefore it might be anticipated that non-reducers would be more distractible.

However, studies investigating the relationship between distractor effects in selective attention and CFQ have given mixed results, with some finding a correlation (Bloem & Schmuck, 1999) and some finding no relationship (Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994). Additionally, some accidents have been linked to not noticing that usually irrelevant information is now relevant. For instance, an account of the Three Mile Island incident suggested that *“operators simply didn't look at the other [indicator lights], never expecting the [valves] to be closed because they were always open during operation”* (Johnson, n.d.). It has been suggested that an increased number of accidents is linked to a high score on the CFQ (Larson, Alderton, Neideffer, & Underhill, 1997) and the CFQ can be used to predict accidents (Wallace & Vodanovich, 2003). Wallace and Vodanovich suggest that accidents may occur due to a failure to process information, as the attentional capacity has been exceeded.

This may suggest that a high score on the CFQ could be correlated with being a reducer.

Either way it would seem that the CFQ could predict an individual's likelihood of using Information Reduction. The CFQ asks participants to rate on a scale from 'very often' to 'never' the frequency with which they have made minor mistakes in the last six months.

An example question is:

Do you fail to hear people speaking to you when you are doing something else?

The full set of 25 questions can be found in Appendix 3.

8.2.3 Trust in memory

Since some participants in the multiple-triplet task indicated on their questionnaires that they continued to count through the alphabet because they did not trust their memory, it was thought that it might be useful to explore whether this had a bearing on the use of Information Reduction. It has previously been suggested that trust in memory affected performance on an alphabet arithmetic task (White, Cerella, & Hoyer, 2007). Although initially developed for use with a patient population, the Squire Subjective Memory Questionnaire (SSMQ) (Squire et al., 1979) has been used to examine trait trust in memory in non-clinical populations as well (Van Bergen, Jelicic, & Merckelbach, 2009; van Bergen, Brands, Jelicic, & Merckelbach, 2010). It has been shown to have a one-dimensional structure, with internal consistency and satisfactory test-retest reliability. It correlates positively with an objective measure of memory (the Auditory Verbal Learning Test) (Van Bergen et al., 2009), showing that in general people are well-calibrated. The SSMQ correlates negatively with the CFQ – as trust in memory increases, then self-reported cognitive

failures decrease. In other words, people who are aware that they make everyday cognitive failures are more likely to distrust their memories. Thus if distractibility, as measured by the CFQ, is linked to using Information Reduction, then trust in memory should also be linked. The SSMQ is an 18-item self-rating scale ranging from -4 (disastrous), through 0 (average), to +4 (perfect).

An example question is:

My ability to hold in my memory things I have learned is ...

The full set of questions can be found in Appendix 4.

8.2.4 Cognitive miser

Some cognitive processes occur quickly and intuitively, with little attention or deliberation, whereas others occur more slowly, involving active and conscious work (Frederick, 2005). These two processes have been referred to as System 1 and System 2. System 1 processing is characterised by being unconscious, rapid, effortless and automatic (Böckenholt, 2012), is thought to be involved in implicit learning and could be considered equivalent to automatic processing in Schneider and Shiffrin's (1977; Shiffrin & Schneider, 1977) classification, referred to in the literature review (Chapter 2). A cognitive miser is someone who saves cognitive resources when possible, relying on intuitive reasoning (heuristics) even if this results in errors (Böckenholt, 2012). They do not suppress the response that first comes to mind (Frederick, 2005). Thus misers are considered to only use System 1 processing (Evans, 2008). Whilst Information Reduction has been posited as a conscious process, there would appear to be parallels between the idea of being a cognitive miser, defaulting to the simplest cognitive mechanism (Toplak, West, & Stanovich, 2011), and being a reducer, which involves simplifying stimulus processing and using the response which first comes to mind. Thus this seemed a potential avenue to

explore as a way to differentiate reducers from non-reducers. The basic test for a cognitive miser, the Cognitive Reflection Test (CRT), is a performance measure rather than a self-report measure. It involves three questions (Frederick, 2005), however, this has been increased in recent years with additional items. Frederick now uses a 10-item test (personal communication, 2014), and this was used in this study. The CRT can be used to predict performance on heuristics-and-biases tasks (Toplak et al., 2011), although it is not related to measures of cognitive ability or executive function. The difference between the questions used in the CRT and insight problems is that participants generally have no problem generating a plausible answer, however, this answer is incorrect. The correct answer can be obtained by reasoning and does not require a re-representation of the problem, as for instance the insight box and candle problem (Duncker & Lees, 1945).

An example question from the CRT is:

Mary's mother has 4 children. The younger three are called Spring, Summer and Autumn. What is the name of the oldest?

The intuitive, cognitive miser, response to this is 'Winter', but the correct answer is of course 'Mary'. The full set of questions can be found in Appendix 5.

8.2.5 Personality

Broader aspects of personality may affect the usage of Information Reduction. Personality has been noted to influence cognitive performance (Costa, Fozard, McCrae, & Bosse, 1976) and to be involved in skill development (McCrae & Costa, 1995). The five-factor model (McCrae & Costa, 1987) consists of agreeableness, conscientiousness, extraversion, neuroticism and openness to experience. These have been shown to be stable across the lifespan (Costa et al., 1986; McCrae & Costa, 1994) and to be universal (McCrae & Costa, 1997). Relationships between these

factors and cognitive processes have been found, for example an association between vigilance and openness and extraversion (Uttl, White, Gonzalez, McDouall, & Leonard, 2013). Uttl et al. attribute the correlations in part to being able to determine strategies for task success, so these could be relevant to using a strategy such as Information Reduction. Agreeableness has been found to predict RTs on the Stroop test and scores on the Wisconsin Card Sorting Test, the latter also being predicted by conscientiousness (Jensen-Campbell et al., 2002). Jensen-Campbell et al. link their findings to effortful control: the ability to sustain and shift attention and the ability to voluntarily initiate and inhibit actions. Conscientiousness has been shown to interact with training method, with a method involving repeated practice being more beneficial for knowledge acquisition in less conscientious individuals (Kluge et al., 2011). Those with lower conscientiousness may be less persistent and need a more highly structured situation, such as that provided by practice training, in order to perform well.

Neuroticism but not extraversion was related to performance on a 'difficult' serial learning task, in which less time was allowed (Jensen, 1962). Those scoring more highly for neuroticism performed less well, although neither trait affected the easier task. Nonetheless, it would seem that neuroticism could have an effect on implicit learning. Extraversion has been shown to correlate consistently with differences in remembering and learning (Allsopp & Eysenck, 1975). Extraversion predicted worse performance on two theoretical forms of learning strategy, model free and model-based (Skatova, Chan, & Daw, 2013). The model-free strategy consists of learning to repeat rewarded actions whereas model-based algorithms learn a map or model of the task structure to guide action. Either of these could potentially be related to using Information Reduction. In relation to motor movements, extraverts have been reported to value speed more than accuracy, whilst

introverts value accuracy over speed (Eysenck, 1967). If this also applies to other tasks, this would suggest that extraverts would be more likely to be reducers.

Unsworth et al. (2012) found that extraversion was negatively related to the ability to sustain attention on a task, which could suggest that extraverts might more readily adopt a strategy like Information Reduction, if they attend long enough to discover it.

Such results suggest that aspects of personality could have an influence on Information Reduction. The actual inventory, which consists of 240 items is not freely available, however an open source with similar questions has been established – the International Personality Item Pool (Goldberg et al., 2006; <http://ipip.ori.org/>). This offers a 50-item scale (10 per factor, with 5 positively keyed and 5 negatively keyed) and a 100-item scale (20 per factor, with 10 positively keyed and 10 negatively keyed). In order to keep the questionnaire to a reasonable length, the 50 item scale was chosen for this study. The full set of questions can be found in Appendix 6.

8.3 METHOD

The questionnaires were set up in Qualtrics (Qualtrics, Provo, UT) and followed the post-testing questionnaire which was administered to all participants (Appendix 1). After participants had returned their datafiles they were sent a link to the questionnaires. All participants in Experiment 4, explicit instruction, and some of the participants in Experiment 5, near transfer, were asked to complete the Dickman impulsivity scale, the CFQ and the SSMQ. For the impulsivity scale questions were presented to participants with functional and dysfunctional alternated. Participants in Experiment 5, far transfer, and some of those who took part in near transfer, were asked to complete the IPIP scale and the CRT. For the five personality types the questions were presented to participants in mixed order: a positively keyed item for

each facet (5 questions, one for each attribute), then a negatively keyed item for each type, followed by another positively keyed item for each etc.

At the start of the survey the participants were told:

In this survey you will be asked some questions about the way you feel and act, which will be analysed along with your data from the experiment you have already completed, to determine if particular personality types perform in certain ways on the task.

The survey consists of several pages and there will be a progress bar at the bottom to show how far through you are. Some are multiple-choice questions, and some require you to indicate your response on a scale - please answer with your first thought and try to answer all questions. Sometimes you may feel that you want to give a broader response than is allowed, but only one response can be recorded, so give the response which reflects your first inclination.

They were also reminded of their right to withdraw, that their data would be held confidentially and that it would not be possible for them to be identified from the results.

The Dickman Impulsivity questions were simply introduced as multiple-choice questions, and each had a radio button to select for true or false. The CFQ was introduced by:

*The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. Please indicate how often these things have happened to you **in the last six months**.*

Answers to the CFQ were by selecting the appropriate radio button for one out of: Never, Rarely, Sometimes, Quite often, Very often. The SSMQ was introduced by:

The following questions ask you to rate your memory on a scale of -4

(disastrous) to +4 (perfect)

and each question had radio buttons to select for the response on a nine-point scale.

The introduction to the personality questions was:

Phrases describing behaviours

On the following pages, there are phrases describing people's behaviours.

*Please use the rating scale below each to describe how accurately each statement describes **you**. Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same gender as you are, and roughly your same age. Please read each statement carefully, and then fill in the bubble that corresponds to the number on the scale.*

The response options were: Very Inaccurate; Moderately Inaccurate; Neither Inaccurate nor Accurate; Moderately Accurate; Very Accurate. The CRT was preceded by:

Below are 10 problems that vary in difficulty. Try to answer as many as you can.

The answers were given in free-text boxes.

Some questionnaires were not completed at all and of those returned, some questions were omitted by some participants, so not all could be included in all the analyses. There were a total of 46 participants in shapes tasks and 49 participants in multiple-triplet tasks who returned questionnaires examining impulsivity, distractibility and trust in memory. There were a total of 52 participants in shapes tasks and 46 participants in multiple-triplet tasks who returned questionnaires examining personality and cognitive miserliness.

8.4 RESULTS

Since these experiments have indicated that there is not a simple dichotomous split between reducers and non-reducers, and that some do not appear to be aware of Information Reduction, despite apparently using it, it was not felt appropriate to analyse the data by using median splits to create categorical variables for logistic regression. The analyses carried out previously (Edmunds, 2005) showed that all the variables tested, such as error rates, differences in RT or slopes, gave similar results. Therefore it was decided to continue with using error rate to irregular stimuli in the test block, as a proxy measure of whether or not someone was a reducer, and this was correlated with the score from each of the scales.

The possible ranges of scores for the various questionnaires and the ranges obtained are shown in Table 8.1. The correlations for each measure with the error rate to irregular stimuli are shown in Table 8.2.

As can be seen in Table 8.2, only one significant result was obtained: there was a significant negative correlation between extraversion and error rate for those who had taken part in the shapes tasks, $r(41) = -.482$, $p = .001$. As the error rate increased the extraversion score reduced – in other words, those showing more reduction by ignoring the irregular shapes in the test block were more introverted. A scatterplot showing the scores by self-report type is shown in figure 8.1. All other correlations for shapes tasks yielded $p > .2$. For multiple-triplet no significant correlations were found, but distractibility, agreeableness, trust in memory and CRT may be worthy of further investigation. All other correlations for multiple-triplet tasks yielded $p > .1$, with most having $p > .4$.

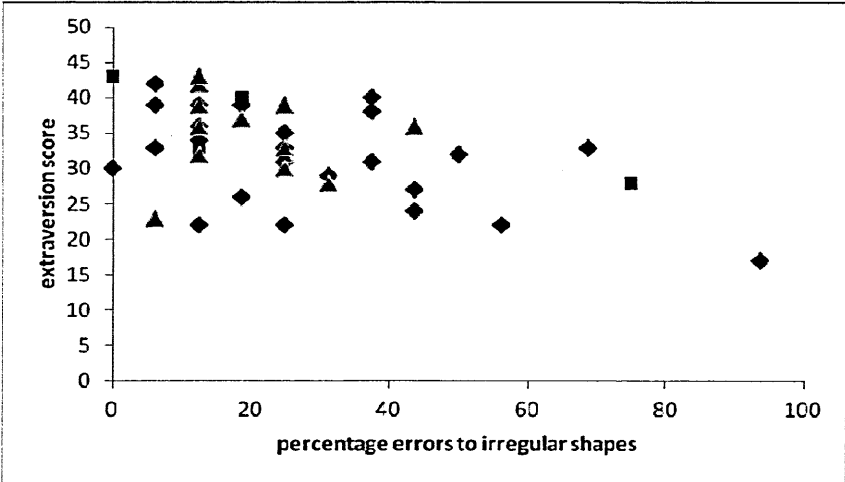
Table 8.1: Range of scores possible and obtained for the various measures

Questionnaire	Minimum score possible	Maximum score possible	Minimum score obtained	Maximum score obtained
Functional impulsivity	11	22	14	21
Dysfunctional impulsivity	12	24	14	22
CFQ	25	125	39	98
SSMQ	18	162	68	157
Agreeableness	10	50	24	47
Conscientiousness	10	50	22	50
Extraversion	10	50	13	43
Neuroticism	10	50	12	46
Openness to experience	10	50	21	49
CRT (miserly score)	0	10	0	10

Table 8.2: Correlations for scores on each questionnaire against error rate to irregular stimuli

Questionnaire	Correlation (multiple-triplet task)	Correlation (shapes task)
Functional impulsivity	$r(43) = -.10, p = .507$	$r(44) = -.03, p = .863$
Dysfunctional impulsivity	$r(44) = -.02, p = .872$	$r(44) = .10, p = .532$
CFQ	$r(47) = -.24, p = .093$	$r(39) = -.06, p = .710$
SSMQ	$r(43) = .26, p = .091$	$r(39) = .11, p = .509$
Agreeableness	$r(44) = -.27, p = .073$	$r(48) = .04, p = .799$
Conscientiousness	$r(45) = -.20, p = .189$	$r(49) = -.18, p = .218$
Extraversion	$r(41) = .02, p = .897$	$r(41) = -.48, p = .001$
Neuroticism	$r(43) = .11, p = .468$	$r(49) = .13, p = .370$
Openness to experience	$r(46) = -.04, p = .774$	$r(49) = -.18, p = .216$
CRT (miserly score)	$r(44) = .26, p = .082$	$r(50) = -.05, p = .735$

Figure 8.1: extraversion score and error rate to irregular shapes by self-report type



Key: ◆ explicitly expressed regularity and indicated use of Information Reduction strategy
■ aware of regularity but continued checking irrelevant elements
▲ did not verbally express regularity

8.5 DISCUSSION

Overall, it would seem that none of the personality or processing traits tested have any bearing on whether someone is a reducer or not, which is surprising given the range of other areas where these individual differences have been detected. However, results from the various experiments reported in chapters 4-9 suggest that the exact nature of task and training conditions have a considerable effect on the use of Information Reduction. Therefore it may be that all differences observed in whether reduction is used or not are due to the type of task or to the training conditions. On the other hand, the effect of changes to task and training conditions could mask any individual differences, or they may only be evident in certain situations. For example, Forster and Lavie (2007) found that distractibility accounted for differences in participant performance at low perceptual load, but high perceptual load eliminated measurable differences.

Implicit learning is thought by some to be an evolutionarily old process (Reber and Allen, 2009) and less subject to individual difference effects and it has been

shown that there is no relationship between extraversion and incidental learning (Imam, 1974). So it would seem that if individual differences do have an effect on Information Reduction they must act either at the stage where the implicitly learned regularity becomes part of conscious awareness or when the decision to make use of the strategic knowledge is made. If deciding to adopt Information Reduction is mainly a conscious decision which depends largely on judgement of whether it is useful in the particular circumstances, as would be deduced from Haider and Frensch's Information Reduction hypothesis, then this could be more significant than any individual difference between groups.

It is possible that the one significant result seen here, for extraversion in the shapes task, is a statistical artefact created by having one reducer with a relatively low extraversion score. In the multiple-triplet task, which had more reducers, there was no correlation at all between extraversion score and number of errors to irregular stimuli. However, as the two tasks involve diverse cognitive processes and are differentially affected by changes to training conditions, it would not be surprising to find that the tasks were differentially affected by individual differences. If the significant correlation does mean that introverts are more likely to reduce in the shapes task, then reasons why this might be should be explored. Earlier research, outlined in section 8.2.5, was equivocal about whether extraverts or introverts would potentially be the best at reduction.

It has been suggested that introverts have a higher level of cortical arousal and a lower level of inhibition (H. J. Eysenck, 1963). Introverts may be able to make finer discriminations than extraverts, as shown in masking and experiments where a flash of light has to be detected under difficult conditions (H. J. Eysenck, 1967; McLaughlin & Eysenck, 1966). Unsworth et al. (2012) found that introverts were more vigilant than extraverts. This suggests that introverts have better selective

attention, with a better ability to process relevant information and ignore irrelevant, which would explain why introverts may be more able to reduce. Arousal increases in extraverts as the task becomes more demanding, bringing their performance to the same level as introverts (M. W. Eysenck, 1975), and extraverts learn more rapidly than introverts on difficult or complex tasks (M. W. Eysenck, 1976). This could explain why there was no difference seen between extraverts and introverts in the multiple-triplet task.

It could be that the individual measures used, such as the CFQ, are not fine-grained enough, and that measures distinguishing more closely areas such as working, retrospective and prospective memory, and attentional control are required (Unsworth et al., 2012). It may be that individual differences in the various modules of working memory, posited in the Baddeley (1983) model, are important in different tasks – the phonological loop for the multiple-triplet task and the visuo-spatial sketchpad for the shapes task.

Although trait impulsivity was not found to affect whether someone reduces or not, cognitive impulsivity (Leshem & Glicksohn, 2007), which can be assessed by the Matching Familiar Figures test (Carrillo-de-la-Pena, Otero, & Romero, 1993; Kagan, 1966; Leshem & Glicksohn, 2007) and the Trail-Making test (Leshem & Glicksohn, 2007; White et al., 1994), may be relevant. Executive function, a theoretical construct of the higher-order cognitive processes involved in thought and action, such as planning, sequencing and monitoring (Salthouse, Atkinson, & Berish, 2003), is another area where individual differences may affect the use of Information Reduction. Here again, it may be more useful to examine each cognitive operation separately, as executive function may not be a unitary construct. Inhibition of prepotent responses, which can be assessed with the Stroop task (Stroop, 1935), is one such process that may be relevant to Information Reduction. Another construct

which could be relevant to the varied use of Information Reduction seen is that of cognitive style. This is a person's tendency or preference for representing and processing information in a particular way (Newton and Roberts, 2000) such that different strategies for learning and for making inferences are used (Roberts and Newton, 2001). This results in individual differences in strategy use. A number of dichotomies have been suggested between dominant styles, for example, visualisers vs verbalisers and holists vs serialists. There are many other cognitive styles that have been suggested, so careful examination of the literature would be needed before embarking on examining this construct.

Haider and Frensch's Information Reduction hypothesis would seem to suggest that in the right conditions everyone could become a reducer. Consequently, it could be that the area to examine is whether individual differences apply to the length of training required before Information Reduction is adopted, that is, distinguishing those who are 'early' reducers from 'late' reducers. The explicit instruction experiment (Experiment 4, chapter 7) could prove a means by which this could be tested, if a larger number of participants could be recruited. It would probably also need more blocks, to maximise the chances of late reducers finding the strategy – of the six participants tested in the 30-block experiment (Haider & Frensch, 2002), two appeared to need over 15 blocks before discovering the strategy.

Whilst the results presented here serve mainly to eliminate various areas of individual difference as factors involved in whether someone is a reducer or not, this does not mean that other factors, such as working memory or selective attention, or processing styles, do not act at some point in the various cognitive processes occurring.

The next chapter describes the final set of experiments carried out, which examine whether Information Reduction can be transferred from one set of stimuli to another similar set.

Chapter 9 EXPERIMENT 5

TRANSFER TO NEW STIMULI/RULE

9.1 INTRODUCTION

One method used to determine the processes involved in skill acquisition is the use of a transfer design: one task is practised and subsequently another task which shares features is introduced (Proctor & Vu, 2006). The learned response from the first task influences responses in the second (Adams, 1987). Positive transfer occurs when the skill is applicable to the second task and is used to maintain or improve performance. Negative transfer occurs when the skill transferred causes a decrement in performance. The use of the test block in the Alphabet Verification task, the multiple-triplet task and shapes task could be considered examples of transfer tasks in which negative transfer occurs. That is, the skill developed throughout training, of ignoring irrelevant information, is applied even though it (unknowingly) reduces accuracy.

The notion that positive transfer occurs is fundamental to many educational and other training programmes – that what is learned in the ‘classroom’ can be applied to other situations. However, from early days in psychology, it has been clear that there are limitations to transfer. The stimuli, the task, the responses and the generality of any strategy employed, as well as the nature of the practice involved and the generality, and shared nature, of the procedural memory productions required, determine whether, or how successfully, transfer occurs (Adams, 1987; Barnett & Ceci, 2002; Speelman & Kirsner, 1997; Strayer & Kramer, 1994; Taatgen, 2013). For instance, Thorndike and Woodworth found that training in size estimation of rectangles did not enable more accurate estimation of size for other shapes such as

triangles and circles (Woodworth & Thorndike, 1901), although the rather rigid conclusions they came to about the non-involvement of “general faculties” have since been shown to be over-generalisations. Other experiments have shown that transfer can even occur across modalities: pre-training with verbal labels can be transferred to motor responses (McAllister, 1953). However, the performance improvement between modalities is less than that seen within a modality (Proctor et al., 2013). Transfer may also be affected by the development of flexible knowledge or concepts about a task (Müller, 1999), such as an awareness of a strategy like Information Reduction, although if a strategy is stimulus- or task-specific it may not be transferable (Strayer & Kramer, 1994).

One distinction that has been made is between near and far transfer, although the precise nature of what constitutes ‘far’ transfer is a matter of debate (Barnett & Ceci, 2002). When the content and outcomes of training and task are closely matched and both use specific concepts and skills, then near transfer is said to occur (Kim & Lee, 2001). Far transfer could be defined as any type of transfer in which the content differs or where general principles or problem-solving rules need to be employed. In the suggested taxonomy of far transfer outlined by Barnett and Ceci (2002) it is suggested that both the content (what is transferred) and the context (when and where transfer occurs) should differ. Thus the Thorndike and Woodworth experiment may or may not be classified as far transfer, whereas the McAllister one could be. Results from experiments considered by their authors to be ‘far transfer’ are equivocal as to whether transfer occurs or not.

Applying these ideas to Information Reduction tasks, we could categorise the research that has been done so far as ‘near transfer’. Previous experiments which tested transfer in the Alphabet Verification task used structurally similar strings varying only by the initial letters used for the triplet (Haider & Frensch, 1996; Haider

et al., 2005). Thus the training and transfer tasks were very close in terms of both content and in the 'rule' which needed to be transferred: that the validity of the string was determined by the initial triplet. These studies were designed to test whether specific stimuli were being recalled, as Instance Theory would suggest, or if the strategy developed was item-general. The results indicated that the strategy transferred and it was concluded that the speeding seen could not be attributed to automatic instance recall. Hence Information Reduction is seen as a separate and consciously controlled strategy, although as we have shown, not everyone who uses Information Reduction appears to be aware of so doing.

Speelman and Kirsner (2001) investigated whether the performance gains on one task would transfer and indeed lead to further skill improvement on a second, related task, which contained some additional components. They found that skill improvement was disrupted when the second task was introduced and that this effect was exacerbated if the task complexity had increased, but that the amount of prior practice did not seem to be a factor. It was considered that a need to reconceptualise the task on transfer stalled the improvement in the already-learned skill, but that performance did return to pre-transfer levels and then continued to improve as would be predicted by a power-law curve.

Skill acquisition theories such as Logan's (1988) would predict that there would be no positive transfer of the skill, since the instances are different. Anderson's Production rules theory (1987) could accommodate both near and far transfer, since productions developed for one task may also be used in another – transfer will occur more positively the more the productions for the various components overlap (Speelman & Kirsner, 2001) or if productions consist of combinations of task-general 'primitive elements' or 'partial task-general rules' (Taatgen, 2013). This theory would not predict a loss of performance, such as an

increase in RTs, on transfer, since the productions being used would be similar. However, the context in which productions are acquired may affect the efficiency of transfer. Transfer could also be explained by analogical reasoning from declarative knowledge, which could occur for Information Reduction if the participant is consciously aware of using the strategy, although experiments testing analogical transfer suggest that it is not spontaneously used (Gick, 1986). Consequently, transfer tasks could also be used to determine whether there is conscious knowledge of the regularity: if the participant is aware of its existence and what that rule is, then encountering new stimuli which use the same rule, or which also conform to some regularity, would be theorised to result in transfer of the knowledge ('near transfer'). Far transfer could also occur if, being aware of a regularity in the first set of stimuli, participants used this knowledge to search for a new regularity to speed responses to a second set ('far transfer'). This possibility was the basis for the following experiments.

9.2 NEAR TRANSFER

9.2.1 Introduction

Haider and Frensch (1996) and Haider et al. (2005) demonstrated that, having learned the Information Reduction strategy on one set of stimuli, it could be transferred to a previously unseen set of similar, structurally equivalent stimuli. The two sets of stimuli started with different letters of the alphabet: D-H and I-M with the triplet at the start of the string for Haider and Frensch (1996) and E-L and M-T with the triplet being located at the end of the string for Haider et al. (2005). The first experiment repeated each stimulus twice per block, with 400 trials with the first set of stimuli and 400 with the second. As expected, RTs dropped over the first four blocks, rose a little on the unannounced change of stimuli and then fell, although not

to much less than had been achieved at block 4. However, the string-length effect was virtually unaffected by the change in stimuli, demonstrating that the strategy of ignoring the trailing letters had been transferred, even though the participants were taking longer due to having to compute a new set of triplets. The 2005 experiment used a drop in latency of > 1 s between blocks on the first set of stimuli as a measure of a strategy switch. Participants received between 320 and 640 training trials, depending on whether they were deemed to have started using the strategy or not during the experiment, followed by 160 transfer trials. Again latencies increased when the new stimuli were introduced. However, the approximately half of participants classed as reducers were found to return to the performance level, in terms of RT, of the first set of stimuli within two blocks of transfer, whereas those classed as non-reducers did not. There was no block in which irregular strings occurred in either of these experiments, but they do demonstrate that positive transfer can occur in Information Reduction tasks, when the stimuli are very similar. In both experiments the 'rule', the position of the triplet and the digit used, was the same both before and after the stimuli change.

Another implicit learning transfer experiment used the serial reaction time (SRT) task (Schwager et al., 2012). Participants either received 300 trials with no sequence, followed by 180 trials with a 6-item repeating sequence, or 300 trials with one repeating 6-item sequence followed by 180 trials with a different 6-item repeating sequence. Significantly more participants could verbalise at least 4 sequential items from the sequence used at the end of the experiment if they had firstly had experience with another sequence than if they had initially experienced random trials. This was taken as evidence in support of the Unexpected-Event hypothesis. This hypothesis suggests that an unexpected event, such as a feeling of familiarity or a rapid motor response prior to the processing of a stimulus (or even

the appearance of a stimulus in the SRT), triggers an intentional search for an explanation of that event by an explicit reasoning system or, in other words, explicit hypothesis testing. Once the cause of the rapid response has been determined, then the knowledge is applied from that point onwards, resulting in an RT discontinuity at the point of application.

In further analyses, which also showed support for the Unexpected-Event hypothesis, Schwager et al. excluded those who were judged, by a drop in RT, to have explicitly learned the repeating sequence during the first 300 trials, since they could have carried over knowledge of there being a sequence. They did not analyse whether this group were faster at discovering the second sequence they were exposed to than those who showed an RT drop during the second sequence but did not appear to have noticed the first sequence. However, Schwager et al. did show that the RT slowing at transfer was the same for both the 'verbaliser' and the 'non-verbaliser' groups and took this as evidence of implicit learning of the sequence. Thus it seems that an implicitly learned regularity can be positively transferred from one set of stimuli to another structurally similar set.

A further set of studies has examined the effects of transfer between different levels of complexity of otherwise similar stimuli (Doane et al., 1996; Doane et al., 1999; Pellegrino et al., 1991). These experiments required participants to make same/different judgements regarding a set of random polygons of increasing complexity, where complexity referred to the number of vertices. In the first experiment participants were trained with 960 trials where the polygons were either highly similar (difficult group) or less similar (easy group) and this was followed by 960 trials where both the highly similar and less similar polygons were presented to all. Results were that the difficult group were able to adjust rapidly when the new, easier-to-discriminate stimuli were introduced, but that the easy group were

disrupted by the inclusion of the harder-to-discriminate polygons. A 'string-length effect' related to the complexity of the polygons was noted for the difficult group, but at this stage not linked to a strategy. Instead, it was considered that the difficult group had acquired holistic representations and that this was the determining factor in smoothing ease of transfer. The later experiments examined the type of strategy being employed and concluded that those exposed initially to the difficult stimuli were using an Information Reduction-like, but unconscious, strategy whereas those exposed initially to easy stimuli employed an early-terminating feature search. The former strategy facilitated positive transfer whereas the latter resulted in negative transfer effects. In other words, a strategy like Information Reduction could transfer from more difficult stimuli to easy ones, but transfer might not successfully occur with other strategies.

The experiments reported so far all introduced stimuli which were structurally very similar to those initially encountered. This experiment sought to test whether transfer could occur with stimuli that may appear slightly more different, but which utilise the same rule or regularity. In the case of multiple-triplet, the digits of letters to be skipped were changed from being 4-2-2 to 3-3-3 (see Table 9.1), but the initial triplet was always relevant for determining whether the string was correct or not. There is very little published literature where the digit has been changed, but it has been found that the RT to '3' is faster than to '4' and slower than '2' (Brigman & Cherry, 2002), so overall this change was not anticipated to increase the time taken to complete the task. In the case of shapes, the shapes were substituted by 'block' letters, but the different shape was still situated middle right. It was felt from the control experiment (Experiment 1) that Information Reduction was reasonably well established after six blocks of the multiple-triplet task (360 trials) and four blocks of the shapes task (320 trials). However, it was difficult to predict how many transfer

blocks might be needed and this had to be balanced with keeping the experiment to a reasonable length. Consequently there were three transfer blocks (180 trials) for the multiple-triplet task and four transfer blocks (320 trials) for the shapes task. To enable comparison with other experiments, the training blocks were followed by a test block, with irregular versions of the most recently encountered stimuli type. It was hypothesised that transfer of the Information Reduction strategy would occur from the first set of stimuli to the second.

9.2.2 Method

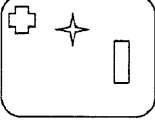
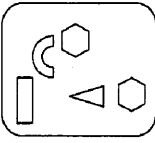
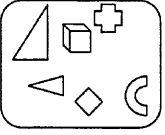
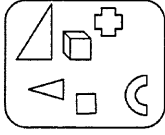
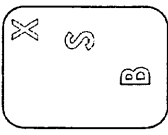
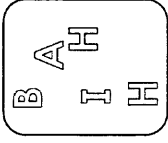
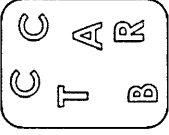
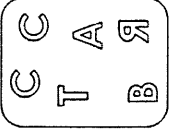
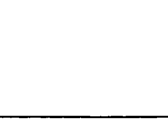
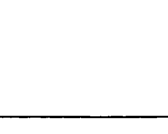
9.2.2.1 *Participants*

There were 101 participants, all Open University students studying psychology, none of whom had participated in other experiments. There were 51 participants (12 male) in the multiple-triplet task and 50 (8 male) in the shapes task. Their ages ranged from 26-59, mean age 41.

9.2.2.2 *Materials*

For each task, one set of stimuli were as used in previous experiments. One new set of stimuli was devised for each. In the multiple-triplet task the interval between each letter was changed from an initial digit of 4, with digits of 2 subsequently, to be 3 throughout. The original stimuli are henceforward referred to as '422-letters' and the new set as '333-letters'. In the shapes task each shape was substituted with a 'block' letter, which was rotated to create the incorrect shape. These are subsequently referred to as 'shapes' and 'letters'. Piloting suggested that both of these new stimuli sets would give Information Reduction. Examples of the various stimuli used are given in Table 9.1.

Table 9.1: Examples of stimuli used

Stimuli type	'Regular correct' stimulus (whole stimulus should be processed initially)	'Regular incorrect' stimulus (processing should cease when error/target/difference found)	Irregular stimulus (used only in test block)
Multiple-triplet 422-letters	B(4)G	B(4)H	B(4)G(2)K
	B(4)G(2)J	B(4)H(2)K	D(4)I(2)M(2)P
	B(4)G(2)J(2)M	B(4)H(2)K(2)N	E(4)J(2)M(2)Q
Multiple-triplet 333-letters	B(3)F	B(3)G	B(3)F(3)K
	B(3)F(3)J	B(3)G(3)K	D(3)H(3)M(3)Q
	B(3)F(3)J(3)N	B(3)G(3)K(3)O	E(3)I(3)M(3)R
Shapes task	<i>Boxes match</i>	<i>Boxes differ - shape middle right in right-hand box rotated</i>	<i>Rotated shape elsewhere in right-hand box</i>
Shapes			 
Shapes task			
Letters			

9.2.2.3 *Procedure*

The procedure for the practice trials was as in Experiment 1 and these reflected the first stimuli set to be seen. Half the participants in the multiple-triplet task saw the first set of stimuli (422-letters) followed by the second set (333-letters) and half saw 333-letters followed by 422-letters. In the shapes task half the participants saw the shapes first followed by the letters and half saw the letters followed by the shapes. The instructions were as in Experiment 1 and the change of stimuli set was unannounced, as was the test block. The stimuli used in the test block were the most recently encountered stimulus set.

Participants also received a post-testing questionnaire asking questions about the task carried out, to gauge awareness and use of the regularity, and also to investigate aspects of individual differences. These individual difference tests were fully described and results presented in chapter 8.

9.2.2.4 *Design*

The within-participants independent variables were ‘string length’ and type of ‘string’: regular correct, regular incorrect or irregular. For the multiple-triplet task the string length was one, two or three triplets and for the shapes task it was 3-6 shapes.

There were 60 strings per block in the multiple-triplet task, with 9 training blocks, giving 540 trials during training. These were divided into 6 blocks with the first set of stimuli (360 trials) and 3 blocks with the second set of stimuli (180 trials). There were 80 shape stimuli per block in the shape matching task, with 8 training blocks, giving 640 training trials. These were given as 4 blocks with each stimulus set (320 trials). For each task half the training stimuli in each block were correct and half were incorrect. Each task had one practice block of 10 stimuli at the beginning and one test block after the training blocks. The test block had some regular incorrect

stimuli replaced with irregular ones – 12 for the multiple-triplet task and 16 for the shapes task.

The dependent variables were response time (RT) to each stimulus and number of stimuli incorrectly responded to in the training blocks and the test block.

9.2.3 Results

The results for the different orders of stimuli sets in each task are presented separately.

9.2.3.1 Accuracy

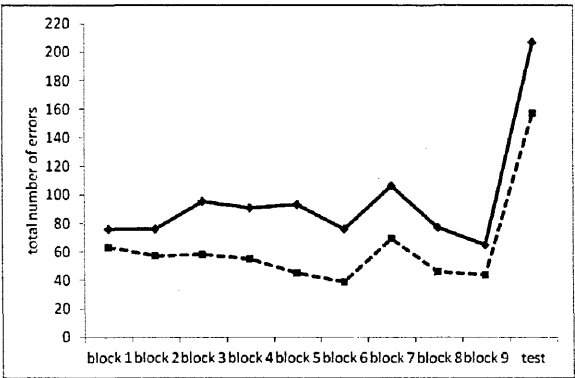
The analysis excluded participants with errors in training of 10% or greater for each trial block. In the multiple-triplet task one was excluded from 422-letters, leaving 23 participants' data, and four were excluded from 333-letters, leaving 23 participants' data. In the shapes task two participants were excluded from shapes, leaving 23 participants' data and two participants were excluded from letters, leaving 23 participants' data.

Table 9.2 shows that similar numbers of errors were made to the 'regular' strings and shapes in the final training block and the test block but more errors were made to the irregular strings or inconsistently placed shapes. Error rates to the irregular stimuli ranged from 0% to 100% for both stimuli sets in the multiple-triplet task. For the shapes task, the overall error rates to the irregular stimuli were 0 to 94% where letters were the second set and 12.5% to 81% where shapes were the second set. Figure 9.1 shows that the total number of errors increased at all changes of stimuli except for the shapes to letters change. The letters to shapes change caused a five times increase in the number of errors, which is far in excess of the increase in errors at the change of stimuli in the multiple-triplet task, which only doubled for

both stimuli sets. However, the number of errors to shapes did reduce in the letters-first shapes task, to the level seen in the shapes-first. Overall though processing the letters was less error-prone than the shapes.

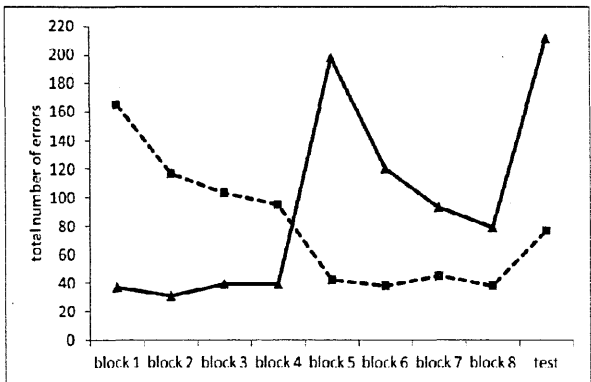
Figure 9.1: change in total number of errors made per block

a) multiple-triplet task



Key: solid line – 333 letters first, broken line - 422-letters-first

b) shapes task



Key: solid line - letters-first, broken line - shapes-first

In the multiple-triplet task, 422-letters-first, 3 of the 23 participants incorrectly categorised all 12 of the irregular strings, with another 6 incorrectly categorising more than half of the irregular strings. For 333-letters-first, 2 participants incorrectly categorised all 12 irregular strings, 4 incorrectly categorised 10 or 11 strings and a further 4 had more than half incorrect. Thus 39% of the participants in 422-letters-first and 43% of the participants in 333-letters-first made a high number of incorrect categorisations.

In the shapes task, shapes-first, 7 out of 23 participants had twice as many errors to irregular than differing letters in the test block, although all except one spotted nearly all of them. One participant incorrectly classified 15 of the irregular stimuli. In letters-first 11 out of 23 participants had twice as many errors to irregular than differing shapes in the test block, with 5 having more than half incorrectly categorised. 30% of participants in shapes-first and 48% in letters-first made at least twice as many errors to the inconsistently placed as to the consistently placed differing stimuli.

Table 9.2: Overall error rates in final training block and test block by stimulus type

		Final training block	Test block
Multiple-triplet task			
422-letters-first (final training block and test block used 333-letters)	correct	4.1%	5.5%
	regular incorrect	2.8%	3.9%
	irregular	-	37.3%
333-letters-first (final training block and test block used 422-letters)	correct	7.%	8%
	regular incorrect	3.9%	9%
	irregular	-	40.9%
Shapes task			
Shapes-first (final training block and test block used letters)	matching	1.3%	1.1%
	differing	2.8%	3.1%
	irregular	-	13.6%
Letters-first (final training block and test block used shapes)	matching	1.6%	1.7%
	differing	7%	11.6%
	irregular	-	35.6%

A one-way repeated measures ANOVA (String Type: regular correct, regular incorrect and irregular) on error rates for the test block showed a significant difference among the trial types for each task. For the multiple-triplet task, 422-

letters-first, string types $F(2,44) = 14.77$, $MSE = 15,367$, $p = .001$, $\eta_p^2 = .402$, with the difference lying between the regular and irregular strings (pairwise comparison: regular correct vs regular incorrect $p = .365$, regular correct vs irregular $p = .001$, regular incorrect vs irregular $p = .001$). For 333-letters-first, $F(2,44) = 19.8$, $MSE = 13,920$, $p < .001$, $\eta_p^2 = .474$, with the difference lying between the regular and irregular strings (pairwise comparison: regular correct vs regular incorrect $p = .296$, regular correct vs irregular $p < .001$, regular incorrect vs irregular $p < .001$). The effect sizes for both were large, although smaller than Experiment 1, suggesting that some of the variance in the error rates is explained by the difference in the stimuli types.

For the shapes task, shapes-first, different shape types, $F(2,44) = 8.83$, $MSE = 2,156$, $p < .006$, $\eta_p^2 = .286$ with the difference lying between the regular and irregular stimuli (pairwise comparison: regular correct vs regular incorrect $p = .071$, regular correct vs irregular $p = .004$, regular incorrect vs irregular $p = .011$). For letters-first, $F(2,44) = 42.36$, $MSE = 11,970$, $p < 0.001$, $\eta_p^2 = .658$, with all shape types being significantly different to each other (pairwise comparison: regular correct vs regular incorrect $p < .001$, regular correct vs irregular $p < .001$, regular incorrect vs irregular $p < .001$). Both effect sizes are large; that for shapes-first is smaller than Experiment 1, whereas that for letters-first is larger than Experiment 1. This suggests that when the stimuli were letters there was not such an effect of varying the type from regular to irregular, but when the stimuli were shapes there was a large effect of varying the type from regular to irregular.

9.2.3.2 *Response times*

In the multiple-triplet task for 422-first there was a significant correlation between overall error rate in training and overall RT: $r(21) = -.597$, $p = .003$,

indicating that some or all of the participants may have been using a speed-accuracy trade-off strategy. This is particularly surprising since the first 6 blocks were the same task as has been used in previous experiments, where no correlation has been seen. For 333-first there was no correlation between overall error rate and RT in training: $r(21) = -.208, p = .342$, indicating that there was no speed-accuracy trade-off in this task.

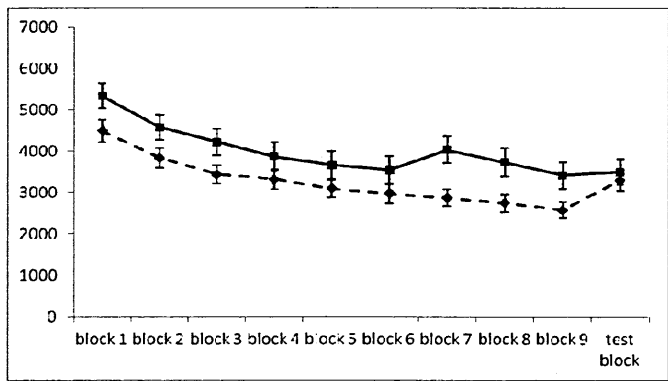
In the shapes task, shapes-first, there was a significant correlation between overall error rate in training and overall RT: $r(21) = -.488, p = .018$, which indicates that some or all of the participants may have been using a speed-accuracy trade-off strategy. Again this is surprising for the same reason as the 422-first multiple-triplet task. For letters-first there was no significant correlation: $r(21) = -.342, p = .111$, indicating that there was no speed-accuracy trade-off in this task.

Figure 9.2 shows that response times decreased overall during each task, although there was an increase at the change in stimuli. RTs for correct stimuli were slower than for incorrect, although all tasks showed some convergence between them, indicating a greater speeding for the correct stimuli.

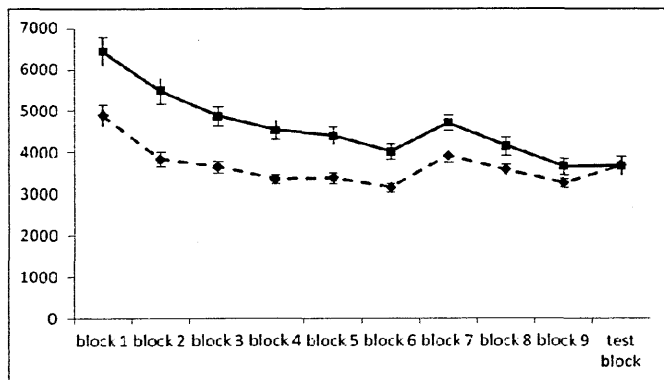
Figure 9.2: change in response times over the course of each task. Error bars represent the standard error of the mean.

Key: solid line – correct stimuli, broken line – incorrect stimuli

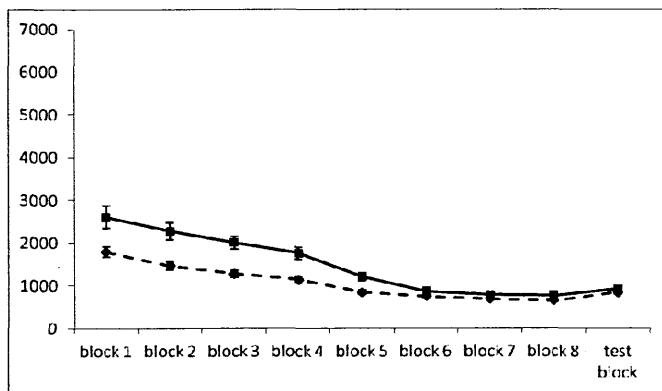
a) Multiple-triplet: 422-first



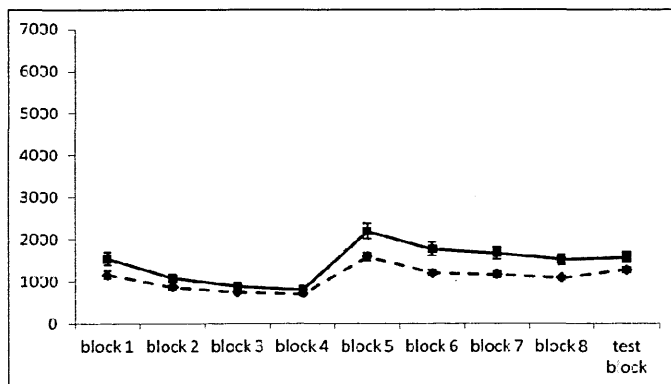
b) Multiple-triplet: 333-first



c) Shapes task: shapes-first



d) Shapes task: letters-first



The results of repeated measures ANOVA on the RTs by Block for each stimulus set are given in Table 9.3. RTs reduced across blocks with similar stimuli, but tended to increase when the stimuli set changed and in the test block when irregular stimuli were introduced. At both points this increase was not always significant. The only exception was the change from shapes to letters in the shapes

Table 9.3: repeated-measures ANOVA on RTs for different stimuli sets and change across sets in the two tasks

Task	Blocks		Change
Multiple-triplet	Block1-block6	$F(5,110) = 63.03$, $MSE = 21,714,667$, $p < .001$, $\eta_p^2 = .741$	Significant decrease
	Block6-block7 (change of stimuli)	$F(1,22) = 2.85$, $MSE = 456,502$, $p = .106$, $\eta_p^2 = .114$	Non-significant increase
422-letters-first	Block7-block9	$F(2,44) = 15.00$, $MSE = 1,515,713$, $p < .001$, $\eta_p^2 = .405$	Significant decrease
	Block9-test	$F(1,22) = 20.89$, $MSE = 1,804,887$, $p < .001$, $\eta_p^2 = .487$	Significant increase
Multiple-triplet 333-letters-first	Block1-block6	$F(5,110) = 55.59$, $MSE = 28,949,966$, $p < .001$, $\eta_p^2 = .716$	Significant decrease
	Block6-block7 (change of stimuli)	$F(1,22) = 88.63$, $MSE = 5,988,436$, $p < .001$, $\eta_p^2 = .80$	Significant increase
	Block7-block9	$F(2,44) = 26.29$, $MSE = 4,911,375$, $p < .001$, $\eta_p^2 = .544$	Significant decrease
	Block9-test	$F(1,22) = 2.08$, $MSE = 537,231$, $p = .163$, $\eta_p^2 = .086$	Non-significant increase
Shapes shapes-first	Block1-block4	$F(3,66) = 34.45$, $MSE = 5,410,444$, $p < .001$, $\eta_p^2 = .61$	Significant decrease
	Block4-block5 (change of stimuli)	$F(1,22) = 54.93$, $MSE = 2,116,386$, $p < .001$, $\eta_p^2 = .714$	Significant decrease
	Block5-block8	$F(3,66) = 30.15$, $MSE = 698,188$, $p < .001$, $\eta_p^2 = .578$	Significant decrease
	Block8-test	$F(1,22) = 64.9$, $MSE = 321,315$, $p < .001$, $\eta_p^2 = .747$	Significant increase
Shapes letters-first	Block1-block4	$F(3,66) = 35.18$, $MSE = 3,850,203$, $p < .001$, $\eta_p^2 = .615$	Significant decrease
	Block4-block5 (change of stimuli)	$F(1,22) = 88.02$, $MSE = 14,915,456$, $p < .001$, $\eta_p^2 = .8$	Significant increase
	Block5-block8	$F(3,66) = 41.65$, $MSE = 1,925,913$, $p < .001$, $\eta_p^2 = .654$	Significant decrease
	Block8-test	$F(1,22) = 7.77$, $MSE = 137,114$, $p = .011$, $\eta_p^2 = .261$	Significant increase

task, where there was a significant decrease, indicating that the letters were easier to process.

9.2.3.3 *“String length effect”*

The relative changes in RT for the different ‘string lengths’ is used as a measure of whether Information Reduction occurs: if participants learn to process only the relevant part of the stimulus then the RT for longer correct stimuli should reduce to a greater extent than that to shorter correct stimuli. On the whole all incorrect stimuli should be processed equally quickly, since processing can cease once the inaccuracy/difference has been determined. This relative change can be tested by carrying out a linear regression with stimulus length as predictor to obtain a slope per participant and block, followed by a one-way ANOVA on these slopes.

9.2.3.3.1 *Multiple-triplet task*

For correct strings in 422-letters-first, there was a significant decrease in slopes over the first set of stimuli, block 1 – 6, $F(5,110) = 18.68$, $MSE = 621,678$, $p < .001$, $\eta_p^2 = .459$ and a non-significant decrease in slopes over the second set of stimuli, block 6 – 9, $F(2,44) = 2.28$, $MSE = 124,539$, $p = .13$, $\eta_p^2 = .094$. At the change in stimuli there was a non-significant decrease in slopes block 6 – 7, $F < 1$ and there was a significant increase in slopes from the final training block to the test block, block 9 – test, $F(1,22) = 12.57$, $MSE = 922,432$, $p = .002$, $\eta_p^2 = .364$.

For incorrect strings in 422-letters-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 6, $F(5,110) = 7.14$, $MSE = 132.522$, $p < .001$, $\eta_p^2 = .245$ but a non-significant decrease in slopes for the second set of stimuli, block 7 – 9, $F(2,44) = 2.12$, $MSE = 28,184$, $p = 0.143$, $\eta_p^2 = .088$. At the change in stimuli there was a non-significant increase in slopes block 6 – 7, $F(1,22) < 1$ and

there was a significant increase in slopes from the final training block to the test block, block 9 – test, $F(1,22) = 29.13$, $MSE = 991,735$, $p < .001$, $\eta_p^2 = .57$.

The effect size for both correct and incorrect strings over the first part of training was large and similar to that seen in Experiment 1, so here it can be suggested that there was an effect of increased speeding for the longer strings. Although the reduction in slopes was not significant over the second part of training, there was a medium-sized effect, which suggests that there was some speeding happening.

For correct strings in 333-letters-first, there was a significant decrease in slopes over the first set of stimuli, block 1 – 6, $F(5,110) = 15.85$, $MSE = 1,327,607$, $p < .001$, $\eta_p^2 = .419$ and a significant decrease in slopes over the second set of stimuli, block 6 – 9, $F(2,44) = 24.74$, $MSE = 630,656$, $p < .001$, $\eta_p^2 = .529$. At the change in stimuli there was a non-significant decrease in slopes, block 6 – 7, $F(1,22) < 1$ and block 9 – test, $F(1,22) < 1$. The effect sizes were large, suggesting that there was an effect of more speeding for the longer strings with both stimuli sets.

For incorrect strings in 333-letters-first, there was a non-significant decrease in slopes for the first set of stimuli, block 1 – 6, $F(5,110) = 1.81$, $MSE = 96,852$, $p = .076$, $\eta_p^2 = .168$. There was a non-significant increase in slopes for the second set of stimuli, block 6 – 9, $F(2,44) < 1$, as well as a non-significant increase at the change of stimuli, block 6 – 7, $F(1,22) < 1$, and a significant increase from the final training block to the test block, block 9 – test, $F(1,22) = 5.69$, $MSE = 422,333$, $p = .026$, $\eta_p^2 = .206$.

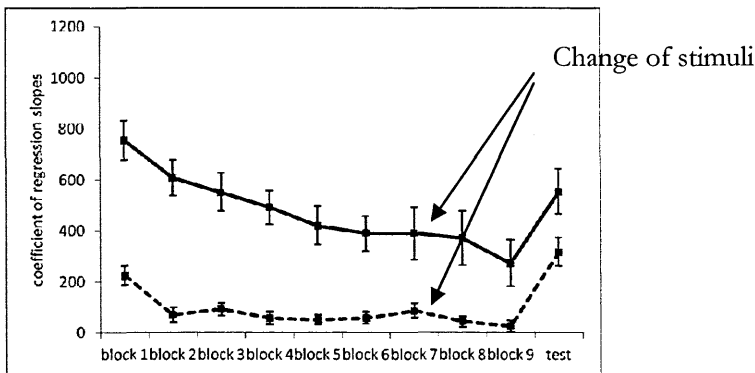
These results suggest that Information Reduction was established with both the 422-letters-first and the 333-letters-first and transferred to the second set of stimuli, at least for some of the participants. The changes in regression slopes are presented graphically in figure 9.3. The slopes for correct and incorrect strings did

not fully converge by the end of training for either 422-letters-first or 333-letters-first.

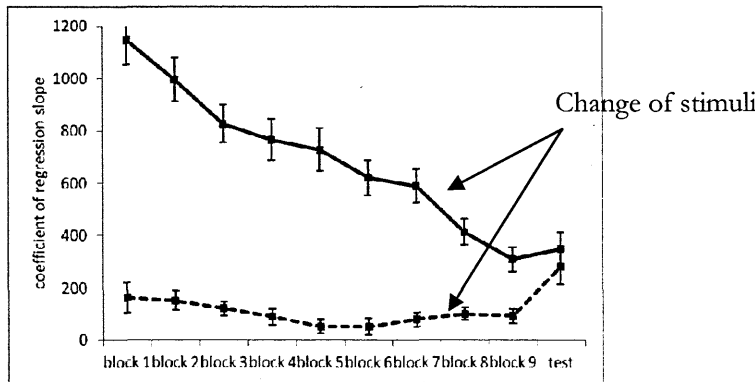
Figure 9.3: Multiple-triplet task, the change in coefficient of regression slopes plotted by block (error bars represent the standard error of the means)

Key: solid line - correct strings, broken line - incorrect strings

a) 422-letters-first



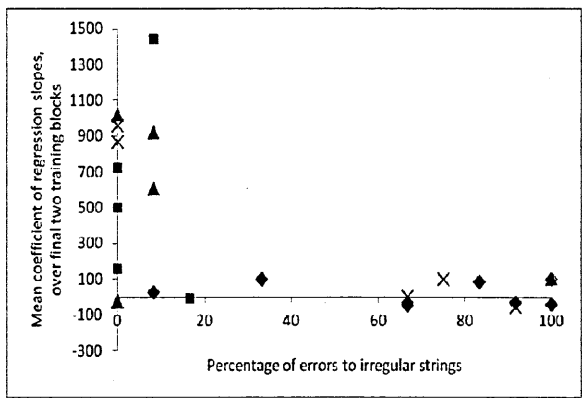
b) 333-letters-first



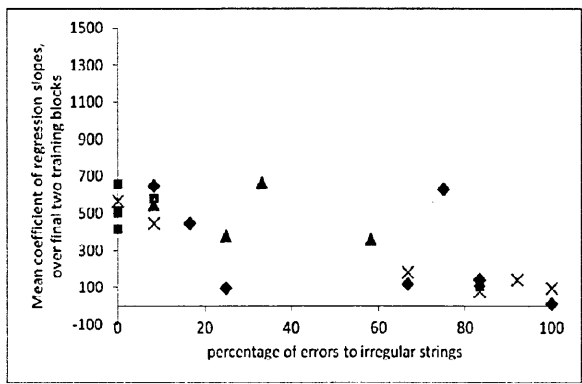
The correlation of the regression coefficient averaged over the final two training blocks and the error rates to irregular stimuli was significant for 422-letters-first, $r(21) = -.564$, $p = .005$ but not for 333-letters-first, $r(21) = -.208$, $p = .342$. Figure 9.4 shows scatterplots of the two measures, also indicating whether the participant spotted the Information Reduction shortcut and whether they used it or not.

Figure 9.4: Scatterplots showing the regression slopes averaged over the final two training blocks against the percentage of errors to the irregular stimuli, indicating whether they found a shortcut or not.

a) 422-letters-first



b) 333-letters-first



Key:
 ◆ explicitly expressed regularity and indicated use of Information reduction
 ■ aware of regularity but continued checking irrelevant elements
 ▲ did not verbally express regularity
 X no questionnaire returned

It can be seen that there are nine reducers (39%) in 422-letters-first, although three of those may have only been partially using the strategy, and eight reducers (35%) in 333-letters-first, although two of these may have only partially used the strategy. It was not possible to distinguish from the questionnaire answers if the strategy had been noticed on the first stimuli set, but was not applied, or only partially applied, on the second set. Looking at the scatterplots, this may have been the case with some participants. Overall, there were fewer participants who seemed

unaware of the strategy than in previous experiments and there was only one non-aware user.

9.2.3.3.2 *Shapes task*

For matching stimuli in shapes-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 4, $F(3,66) = 8.2$, $MSE = 70,320$, $p < .001$, $\eta_p^2 = .272$ and a significant decrease in slopes for the second set of stimuli, block 5 – 8, $F(3,66) = 14.59$, $MSE = 131,447$, $p < .001$, $\eta_p^2 = .399$. At the change in stimuli there was a significant decrease in slopes, block 4 – 5, $F(1,22) = 28.22$, $MSE = 247,677$, $p < .001$, $\eta_p^2 = .562$, and there was a significant increase in slopes from the final training block to the test block, block 8 – test, $F(1,22) = 8.06$, $MSE = 20,116$, $p = .01$, $\eta_p^2 = .268$. The effect sizes for the decrease over training were large for both stimuli types but greater for the letters than for the shapes, suggesting that there was greater speeding for the stimuli with more components.

For differing stimuli in shapes-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 4, $F(3,66) = 12.25$, $MSE = 211.136$, $p < .001$, $\eta_p^2 = .358$ and a non-significant decrease in slopes for the second set of stimuli, block 5 – 8, $F < 1$. At the change in stimuli there was a significant decrease in slopes, block 4 – 5, $F(1,22) = 25.23$, $MSE = 77,891$, $p < .001$, $\eta_p^2 = .534$ and there was an almost significant increase in slopes from the final training block to the test block, block 8 – test, $F(1,22) = 4.185$, $MSE = 15,408$, $p = .053$, $\eta_p^2 = .16$.

These results suggest that Information Reduction was established with the first set of stimuli, the shapes, and was carried over to the second set, the letters, but that many of the irregular stimuli were spotted in the test block. The changes in regression slopes are presented graphically in figure 9.4.

For matching stimuli in letters-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 4, $F(3,66) = 15.3$, $MSE = 235,085$, $p < .001$, $\eta_p^2 = .41$ and a significant decrease for the second set of stimuli, block 5 – 8, $F(3,66) = 7.25$, $MSE = 77,880$, $p = .001$, $\eta_p^2 = .248$. At the change in stimuli there was a significant increase in slopes, block 4 – 5, $F(1,22) = 49.26$, $MSE = 1,079,561$, $p < .001$, $\eta_p^2 = .691$ and there was a non-significant increase in slopes from the final training block to the test block, block 8 – test, $F(1,22) = 3.24$, $MSE = 30,340$, $p = .086$, $\eta_p^2 = .128$. The effect sizes for the decrease over training were large for both stimuli types but greater for the letters than for the shapes, suggesting that there was greater speeding for the stimuli with more components.

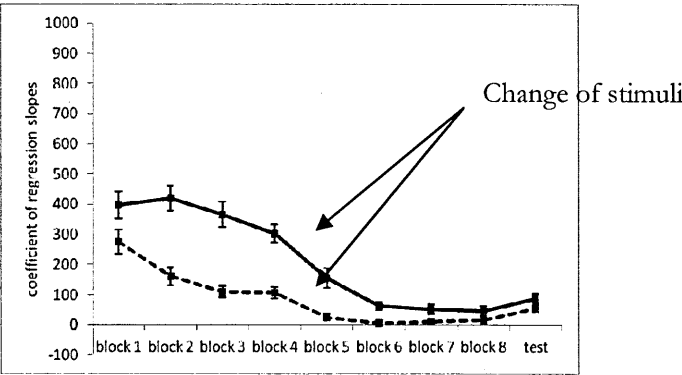
For differing stimuli in letters-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 4, $F(3,66) = 8.69$, $MSE = 36,400$, $p = .001$, $\eta_p^2 = .283$ and a significant decrease for the second set of stimuli, block 5 – 8, $F(3,66) = 6.95$, $MSE = 53,718$, $p = .001$, $\eta_p^2 = .24$. At the change in stimuli there was a significant increase in slopes, block 4 – 5, $F(1,22) = 44.14$, $MSE = 369,071$, $p < .001$, $\eta_p^2 = .667$ and there was a significant increase from the final training block to the test block, block 8 – test, $F(1,22) = 5.4$, $MSE = 29,228$, $p = .03$, $\eta_p^2 = .197$.

These results suggest that Information Reduction was established in the first set of stimuli, the letters, but that the change in stimuli caused processing, especially of the boxes containing more shapes, to slow. Overall, Information Reduction did seem to have been transferred, at least by some of the participants, to the shapes. The changes in slopes are presented graphically in figure 9.5. It can be seen that there was more convergence between the slopes for matching and differing stimuli when the stimuli were block letters than when they were shapes, for both orders of stimuli.

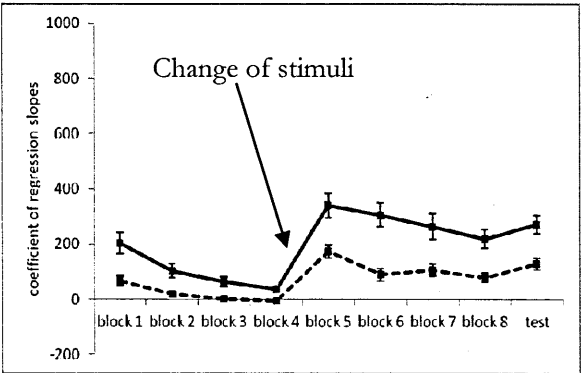
Figure 9.5: Shapes task, the change in coefficient of regression slopes plotted by block (error bars represent the standard error of the means)

Key: solid line – matching stimuli, broken line – differing stimuli

a) shapes-first



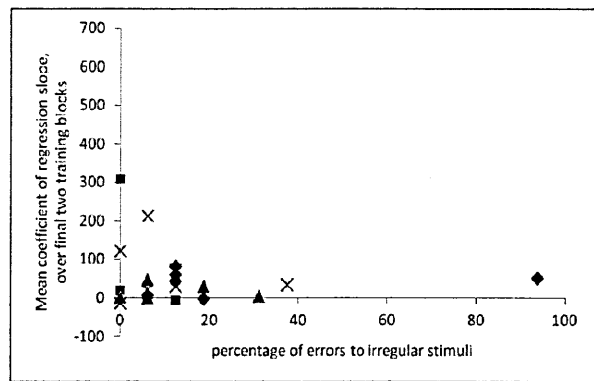
b) letters-first



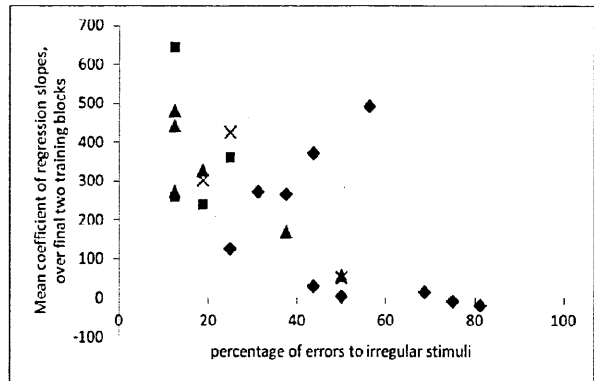
The correlation of the regression coefficient averaged over the final two training blocks and the error rates to irregular stimuli was not significant for shapes-first, $r(21) = -.128$, $p = .562$ but was significant for letters-first, $r(21) = -.676$, $p < .001$. Figure 9.6 shows scatterplots of the two measures, also indicating whether the participant spotted the Information Reduction shortcut and whether they used it or not.

Figure 9.6: Scatterplots showing the regression slopes averaged over the final two training blocks against the percentage of errors to the irregular stimuli, indicating whether they found a shortcut or not.

a) shapes-first task



b) letters-first task



Key:
 ◆ explicitly expressed regularity and indicated use of Information reduction
 ■ aware of regularity but continued checking irrelevant elements
 ▲ did not verbally express regularity
 X no questionnaire returned

It can be seen that all participants who saw shapes followed by letters had low slopes and low numbers of errors to the irregular stimuli, apart from one who had a high number of errors. Those who indicated use of Information Reduction on the questionnaire had a higher number of errors, along with some who showed no awareness. There was one participant who could be classified as a reducer and who had indicated this on the questionnaire. It was apparent from the questionnaires that over-familiarity with letters meant that the differing ones were very easy to spot. Of those who saw letters followed by shapes seven participants seemed to have used

Information Reduction at least partially with the shapes stimuli, although the questionnaire response for one showed no awareness of having done so. There are three (13%) who can be classed as definite reducers, with very low slopes and a very high number of errors to irregular stimuli in the test block.

9.2.4 Discussion

Although it is not possible to establish how many participants were using Information Reduction during presentation of the first set of stimuli, it does appear from the fact that regression slopes significantly declined in all four tasks that it was occurring. For the second set of stimuli the regression slopes in all tasks continued to decline significantly, hinting there was positive transfer of the strategy. This is further support for the results found by Haider and Frensch (1996) and Haider et al. (2005) and is strongly suggestive that Information Reduction is an item-general strategy. For all tasks except letters-first the regression slopes were not affected by the change in stimuli type, although error rates and RTs increased. The increase in error rates and RTs are due to the participants needing to adjust to a new set of stimuli, and for the multiple-triplet, slightly change the computation carried out. This is in line with the results reported by Speelman and Kirsner (2001), where there was disruption on transfer, but then further improvement in skill was seen. The lack of increase in slopes accords with the result found by Haider and Frensch (1996) in their transfer experiment and is evidence that, for three of the tasks, Information Reduction was successfully discovered by some participants in the first set of stimuli and transferred to the second set. If the strategy was not transferred then processing of all elements of the second set of stimuli would occur, resulting in an increase in the regression slopes across the 'string lengths'. These results support the hypothesis that the Information Reduction strategy would transfer to a new set of stimuli when the rule

for applying reduction remains the same, even when the stimuli appear slightly different.

The significant increase in slopes on the change from letters to shapes in the letters-first task, could simply be indicative of the difference in complexity between the two and not of a lack of transfer of the strategy. However, it is possible that a different strategy or type of processing was being used for the letters, which did not transfer successfully, and that the participants had to develop a new strategy with the shapes. Doane et al. (1996; 1999) suggested from their results that the strategy developed depends on the difficulty of the stimuli. The letters proved easy to process, probably due to their familiarity, and may not have led to Information Reduction. Instead it could be that the altered orientation “popped-out” and this gave the impression of being Information Reduction, as the individual letters were no longer processed and thus caused an apparent attenuation of the ‘string length effect’. Nonetheless, it does seem that the strategy used with the shapes in the second part of this task was Information Reduction, since participants were able to verbalise this on their questionnaires and some had a high rate of errors to the irregular stimuli. It is possible that Information Reduction did only develop with the second set of stimuli (shapes), although Doane et al. did not find that the Information Reduction-like strategy occurred overall on transfer from the easy to the difficult stimuli. However their analyses did not test if some participants were able to develop this strategy after transfer. Since there were some definite reducers in our experiment, this suggests that some form of Information Reduction was used with the first set of stimuli, transferred to the second set and became more firmly established.

In comparison with previous experiments, the number of identifiable reducers in the multiple-triplet task (21% for both orders of stimuli) was similar to Experiment 3, speed pressure (23%), and slightly fewer than Experiment 4, explicit instruction (34%). However it was less than half that for Experiment 1, control (64%). In the shapes task, a similar proportion of reducers to the explicit instruction experiment were evident, suggesting that not only was transfer occurring, but also that some of the participants were making full use of Information Reduction. This is unlike Experiment 1, control, where only partial reduction was seen. So it seems that the change in stimuli encourages the use of the strategy in this type of task and future experiments using stimuli where a calculation is not needed could investigate this further. One problem with the current experiment is that the two sets of stimuli in the shapes task were not equally complex and other types of processing may have been occurring, so first of all it would be necessary to equalise the complexity.

In line with Schwager et al.'s results (2012), where experience with one sequence enhanced knowledge of the second, almost all of the identifiable reducers who returned questionnaires were able to verbalise the strategy, in each of the four tasks. This could suggest that successful transfer depends on the participant being consciously aware of the strategy. Nonetheless, there was still one reducer in 422-letters-first and one possible partial reducer in letters-first shapes task who appeared unaware of their use of Information Reduction. A future experiment should aim to determine awareness of the regularity in the first set of stimuli, to explore this further and establish whether some aware participants fail to transfer or whether some non-aware do transfer. It may be that non-aware reducers do not transfer Information Reduction, although given enough practice on the second set of stimuli it may develop again, and this could also be tested in a future experiment. If conscious

knowledge of the regularity is required for transfer to occur, then this supports Haider and Frensch's idea that it is primarily a conscious strategy.

The fact that transfer occurred, even though the stimuli were different in the two parts of each task, and less similar than the stimuli used by Haider and Frensch (1996) and Haider et al. (2005), cannot be explained by one-step retrieval of instances as the driver of the attenuation of the string-length effect. If retrieval of instances were involved then the string-length effect would increase on the change of stimuli in all tasks, until such time as the new instances were memorised and retrieval was faster than carrying out the algorithm. The Production rules theory, or variants of it, such as the PRIMS theory (Taatgen, 2013), can account for the transfer seen, by assuming that many of the productions required for the two sets of stimuli would overlap, although if productions have become composed then the individual steps and overall goal must remain the same for transfer to occur (Speelman & Kirsner, 2001). It would appear to be the case that the productions required overlapped, as attention needs to be focussed on the same place and either a shape examined for a change in orientation or an algorithm executed to count through the alphabet, although the number of counting steps changed from four to three or three to four. It is not known if this slight alteration to the steps required in the production could account for the increase in RT and errors seen at the change in stimuli. However, if an unconscious automatic process, such as the formation of production rules, does wholly or partly underlie the performance improvement and transfer seen (Lee & Anderson, 2001), a mechanism by which the unconscious knowledge becomes verbalisable is required. Schwager et al. (2012) also found an increase in RT on transfer to the new sequence, and took their overall results to be evidence for the Unexpected-Event hypothesis, which explains the conscious knowledge as arising

from explicit hypothesis testing once the performance improvement has been consciously noted.

Overall, then, the results from this experiment support the Information Reduction hypothesis of Haider and Frensch, with implicit learning of a regularity, followed by conscious knowledge that this can be exploited to improve speed on the task. It is not possible to determine which mechanisms are in use, but a combination of Production rules theory and the Unexpected-Event hypothesis might provide an adequate explanation.

9.3 FAR TRANSFER

9.3.1 Introduction

There is much debate in the psychological literature about whether ‘far transfer’ occurs, since many consider that skill transfer can only occur narrowly, where content and context are similar (Rosenbaum et al., 2001). This was the view adopted by Thorndike and Woodworth (1901), who developed a theory of identical elements which suggested that whether, and how much, transfer occurs depends on the extent of commonality and overlap of the elements involved in the two tasks. Barnett and Ceci (2002) consider that one of the reasons for the lack of consistency in far transfer results across the literature is that some experiment tasks are further from the original than others. Transfer may be ‘further’ in applied tasks (eg simulator to real equipment) rather than basic stimulus-response tasks (Proctor et al., 2013), however it does still occur. The amount of practice given or strategy training may also be a factor in how well far transfer occurs (Zelinski, 2009).

Far transfer in Information Reduction could involve transferring knowledge about using a regularity from one set of stimuli to a different set of stimuli which

obey a different rule. There are no known studies testing this kind of transfer. However, there have been other experiments testing transfer of a skill from one domain to another, which could be argued to be further than the transfer of a skill to a similar but not identical set of stimuli. For example, Green and Bavelier (2006) found that the improved visuospatial attention of experienced action-video gamers, and of novices trained with such a game, transferred to improved performance on a perceptual load task and to a test of 'useful field of view', showing that skill on a specific task can be transferred more generally. Karbach and Kray (2009) found that training on task-switching transferred positively to other executive function tasks, such as the Stroop task (Stroop, 1935), to verbal and spatial working memory tasks and to fluid intelligence, measured by tests of figural reasoning and Raven's Progressive Matrices. Another study (Chein & Morrison, 2010) found that four weeks of working memory training not only resulted in improved temporary memory but also generalised to improved performance on the Stroop task and in reading comprehension, although fluid intelligence and reasoning did not improve. The results of these latter two studies suggest that training can affect domain-general mechanisms.

Partial transfer has been shown to occur when a similar task, but with new instances and presented in a different way, is used (Speelman & Kirsner, 1997). In this case, transfer performance was better than at the start of training, but less efficient than at the end of training. This cannot be explained by Instance theory, which would predict that transfer can either be complete, where transfer instances are already available, or does not occur at all. However, it can be accommodated within Production rules theory, as some, but not all, productions developed during training can be used on transfer. Speelman and Kirsner also suggest that strategies may have been acquired in training that were not relevant for the transfer task,

contributing to the partial decrement in performance. Skill and strategy acquisition may depend on the constraints of training, with few variations in stimuli leading to strategies involving retrieval of solution from memory as in Instance theory, whereas a wider range of stimuli in training may lead to more general, more transferable strategies being developed, as suggested by the Production rules theory.

Taatgen (2013) suggests that far transfer can be explained by a model in which ‘primitive information processing elements’ or PRIMS are combined to make general procedures, and these learned procedures can then be used for other tasks enabling faster learning. The procedures can also be ‘composed’ into more task-specific procedures, which can only be transferred to very similar tasks. Far transfer is seen to occur when the task-general procedures of cognitive control can be used in another task, which may seem to be very different. For instance, the model has explained the improved performance seen by Chein and Morrison (2010) and Karbach and Kray (2009).

Applying the learned idea that a strategy exists, rather than the specific nature of what to ignore, could be considered to be akin to analogical problem solving. However, evidence suggests that, at least in the experimental context, analogical reasoning is not spontaneously used (Gick, 1986). Using analogies would be making use of declarative knowledge, and Information Reduction is posited to be a consciously controlled strategy. Testing for far transfer may give further insight into whether there is conscious awareness of the strategy and also metacognition of the ability to transfer what has been learned. Transfer may involve both procedural and declarative knowledge.

In this experiment the stimuli remain very similar to the training set, and performance can be improved by applying a strategy, although the particular ‘rule’

changes. According to the suggested taxonomy of far transfer outlined by Barnett and Ceci (2002), the type of transfer being tested here may not qualify as far transfer. Here the content of transfer would have to be the general principle of the existence of a strategy, rather than the specific nature of that strategy, and the participants must recognise that it is appropriate to use the strategy – they are not given a hint. Both of these are required by the taxonomy. However the context of transfer being tested does not encompass a change of domain, the physical or temporal location, the modality or the social or functional context and thus according to their taxonomy, it could be considered that this transfer, if it occurred, is not very far along the continuum of near-far transfer. Nonetheless, for our purposes it is necessary to distinguish what was tested in this experiment from what was tested in the previous one, so this experiment is designated as being far transfer.

Two new tasks, one using triplets and one using shapes, were devised, which could lead to Information Reduction, as both corresponded to the structural criteria specified in Chapter 4 (Experiment 1):

- i) one element that is relevant to fulfilling the task and at least one other element that is irrelevant
- ii) a variable number of irrelevant elements so that the equivalent of the string-length effect can be detected
- iii) a method of introducing relevance into the formerly redundant element(s) to test for increased errors/return of the string-length effect

For the multiple-triplet task the new rule was that the final letter indicated whether a string was correct or incorrect and for the shapes task the new rule was that the shape bottom left was missing. These tasks are henceforward referred to as end-letters and missing-shapes. Piloting suggested that both of these tasks on their

own led to Information Reduction. The new tasks were combined respectively with the existing 422-letters and orientation-change tasks as used in all previous experiments. As with the near-transfer experiment the order of the two tasks was counterbalanced, with the first task being used in the practice trials and the second task being used in the test block.

The hypothesis was that some participants would successfully transfer the skill to a new set of stimuli, but that fewer would do so than in the near transfer experiment.

9.3.2 Method

9.3.2.1 Participants

There were 101 participants, all Open University students studying psychology, none of whom had participated in other experiments. There were 53 participants (14 male) in the multiple-triplet task and 48 (10 male) in the shapes task. Their ages ranged from 22-60, mean age 41.

9.3.2.2 Materials

For each task, one set of stimuli were as used in previous experiments. One new set of stimuli were devised for each. In the multiple-triplet task the final letter indicated if it was correct or incorrect. Three letters from near the end of the alphabet were used for each (T, V and X for correct and S, U, and W for incorrect), immediately preceded by digits 2-5. To minimise the overall complexity (as a result of piloting), the digit 2 was used for the first one or two triplets in the longer strings. The original stimuli are henceforward referred to as '422-letters' and the new set as 'end-letters'. In the shapes task the differing trials were created by removing the shape from bottom left of the left-hand box. No shape changed orientation in this

set. The two sets are subsequently referred to as ‘orientation-change’ and ‘missing-shape’. Piloting suggested that both of these new stimuli sets would give Information Reduction. Examples of the various stimuli used are given in Table 9.4.

9.3.2.3 Procedure

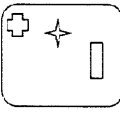
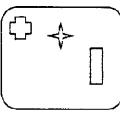
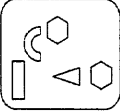


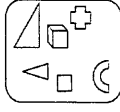
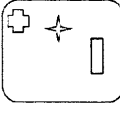
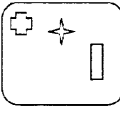

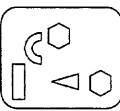
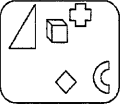
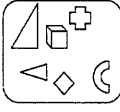
The procedure for the practice trials was as in Experiment 1 and these reflected the first stimuli set to be seen. Twenty-seven participants in the multiple-triplet task saw the first set of stimuli (422-letters) followed by the second set (end-letters) and twenty-five saw end-letters followed by 422-letters. In the shapes task half the participants saw the orientation-change shapes first followed by the missing-shape stimuli and half saw the missing-shape stimuli followed by the orientation-change shapes. The instructions were as in Experiment 1 and the change of stimuli set was unannounced, as was the test block. The stimuli used in the test block were the most recently encountered stimulus set.

Participants also received a post-testing questionnaire asking questions about the task carried out, to gauge awareness and use of the regularity, and also to investigate personality factors: conscientiousness, agreeableness, openness to experience, extraversion and neuroticism; as well as the Cognitive Reflection Test (Frederick, 2005) which aims to establish if the participant is a cognitive miser. These individual difference tests were fully described and results presented in chapter 8.

9.3.2.1 Design

The within-participants independent variables were ‘string length’ and type of ‘string’: regular correct, regular incorrect or irregular. For the multiple-triplet task the string length was one, two or three triplets and for the shapes task it was 3-6 shapes.

Table 9.4: Examples of stimuli used

Stimuli type	‘Regular correct’ stimulus (whole stimulus should be processed initially)	‘Regular incorrect’ stimulus (processing should cease when error/target/difference found)	Irregular stimulus (used only in test block)
Multiple-triplet task 422-letters	B(4)G B(4)G(2)J B(4)G(2)J(2)M	B(4)H B(4)H(2)K B(4)H(2)K(2)N	B(4)G(2)K D(4)I(2)M(2)P E(4)J(2)M(2)Q
Multiple-triplet task End-letters	R(5)X M(2)P(5)V J(2)M(2)P(3)T	Q(4)W L(2)O(2)S J(2)M(2)P(3)U	Q(5)W M(2)P(4)V J(2)M(2)P(2)S
Shapes task orientation-change	<i>Boxes match</i>  	<i>Boxes differ - shape middle right in right-hand box rotated</i>  	<i>Rotated shape elsewhere in right-hand box</i>  
Shapes task missing-shape	<i>Boxes match</i>  	<i>Boxes differ - shape bottom left in left-hand box missing</i>  	<i>Missing shape elsewhere in left-hand box</i>  

In the multiple-triplet task there were 60 strings per block of 422-letters for the first set of training blocks. The 72 stimuli created for end-letters were presented as 60 randomly selected in each of 6 blocks, with all stimuli used 5 times each throughout the experiment. Thus the first set of training blocks had 360 trials for both stimuli types. The second set of training blocks consisted of 3 blocks each with 72 stimuli (216 trials). Twelve of the 422-letters, with 4 from each length, were selected for the additional trials in each block. There were 80 shape stimuli per block in the shape matching task, with 8 training blocks, giving 640 training trials. These were given as 4 blocks with each stimulus set (320 trials). In each task half the training strings in each block were correct and half were incorrect. Each task had one practice block of 10 stimuli at the beginning and one test block after the training blocks. The test block had some regular incorrect stimuli replaced with irregular ones – 12 for the multiple-triplet task and 16 for the shapes task.

The dependent variables were response time (RT) to each stimulus and number of stimuli incorrectly responded to in the training blocks and the test block.

9.3.3 Results

The results for the different orders of stimuli sets in each task are presented separately.

9.3.3.1 Accuracy

The analysis excluded participants with errors in training of 10% or greater for each trial block. In the multiple-triplet task five were excluded from 422-letters-first, leaving 23 participants' data, and two were excluded from end-letters-first, leaving 23 participants' data. In the shapes task one participant was excluded from orientation-change-first, leaving 21 participants' data and four participants were excluded from missing-shape-first, leaving 22 participants' data.

Table 9.5 shows that similar numbers of errors were made to the ‘regular’ strings and shapes in the final training block and the test block but more errors were made to the irregular strings or inconsistently placed shapes. Generally more errors were made to the regular incorrect stimuli in the test block than in training but still fewer than the errors to the irregular stimuli. Error rates to the irregular stimuli ranged from 0% to 43% for 422-letters-first and from 0% to 100% for end-letters-first in the multiple-triplet task. For the shapes task, the overall error rates to the irregular stimuli were 0 to 81% for orientation-change-first and 0% to 50% for missing-shape-first.

Table 9.5: Overall error rates in final training block and test block by stimulus type

		Final training block	Test block
Multiple-triplet task			
422-letters-first (final training block and test block used end-letters)	correct	6.2%	5.2%
	regular incorrect	6%	14.8%
	irregular	-	18%
end-letters-first (final training block and test block used 422-letters)	correct	6.6%	9.4%
	regular incorrect	5.4%	6.9%
	irregular	-	37.9%
Shapes task			
orientation-change-first (final training block and test block used missing-shape)	matching	1%	3.2%
	differing	3.5%	3.2%
	irregular	-	30.1%
missing-shape-first (final training block and test block used orientation-change)	matching	0.8%	2.3%
	differing	7.2%	11.2%
	irregular	-	23.9%

In the multiple-triplet task, 422-letters-first, 3 of the 23 participants had twice as many errors to irregular than incorrect strings in the test block and no participant had more than half of the irregular stimuli incorrectly categorised. For end-letters-first, 10 out of 23 participants had twice as many errors to irregular than to incorrect strings in the test block, with 4 incorrectly categorising all the irregular stimuli and a further 2 having more than half of the irregular stimuli incorrectly categorised. Thus 13% of the participants in 422-letters-first and 43.5% of the participants in end-letters-first made a high number of incorrect categorisations. The change in proportion of errors made per block is shown in figure 9.7, which indicates that the participants were affected by the change in rule, and had not fully adjusted to the new rule so that they spotted many of the irregular strings. Although the overall changes in error rate are similar for both tasks, the way these errors were distributed across the participants varies.

In the shapes task, orientation-change-first, 17 out of 21 participants had twice as many errors to irregular than differing missing-shapes in the test block, with 3 having more than half of the irregular stimuli incorrectly categorised. In missing-shape-first 8 out of 22 participants had twice as many errors to irregular than differing shapes in the test block, with 2 having half the irregular shapes incorrectly categorised. Thus 81% of participants in orientation-change-first and 36% in missing-shape-first made at least twice as many errors to the inconsistently placed as to the consistently placed differing stimuli. The change in errors made per block is shown in figure 9.7, which indicates that those in orientation-change-first do not seem to have been affected by the change in rule, and in fact adopted the new rule so that more irregular stimuli were missed, whereas in missing-shape-first there was a increase in errors from block 4 to block 5 and it seems as if the four blocks of changed orientation was not enough to become totally used to what the changes

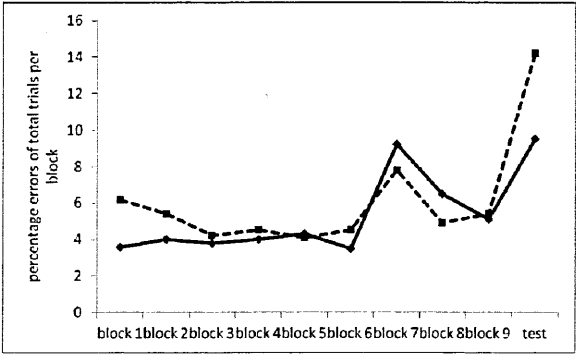
were, so they still had quite a high error rate to differing shapes in the final training block.

A one-way repeated measures ANOVA (String Type: regular correct, regular incorrect and irregular) on error rates for the test block showed a significant difference among the trial types for each task. For the multiple-triplet task, 422-letters-first, $F(2,44) = 6.53$, $MSE = 1,213$, $p = .008$, $\eta_p^2 = .229$, with significant differences between the correct strings and the incorrect ones, but not between the regular incorrect and the irregular (pairwise comparison: regular correct vs regular incorrect $p = .037$, regular correct vs irregular $p < .001$, regular incorrect vs irregular $p = .419$). For end-letters-first, $F(2,44) = 13.67$, $MSE = 12,361$, $p = .001$, $\eta_p^2 = .383$, with the difference lying between the regular and irregular strings (pairwise comparison: regular correct vs regular incorrect $p = .177$, regular correct vs irregular $p = .002$, regular incorrect vs irregular $p = .001$). The effect sizes were large, although smaller than Experiment 1, suggesting that some of the variance in the error rates is explained by the difference in the stimuli types.

For the shapes task, orientation-change-first, different shape types, $F(2,40) = 34.67$, $MSE = 9,671$, $p < .001$, $\eta_p^2 = .634$ with the difference lying between the regular and irregular stimuli (pairwise comparison: regular correct vs regular incorrect $p = .97$, regular correct vs irregular $p < .001$, regular incorrect vs irregular $p < .001$). For missing-shape-first, $F(2,42) = 32.73$, $MSE = 2,677$, $p < .001$, $\eta_p^2 = .609$, with all shape types being significantly different to each other (pairwise comparison: regular correct vs regular incorrect $p = .001$, regular correct vs irregular $p < .001$, regular incorrect vs irregular $p < .001$). The effect sizes were large, and larger than Experiment 1, suggesting that some of the variance in the error rates is explained by the difference in the stimuli types.

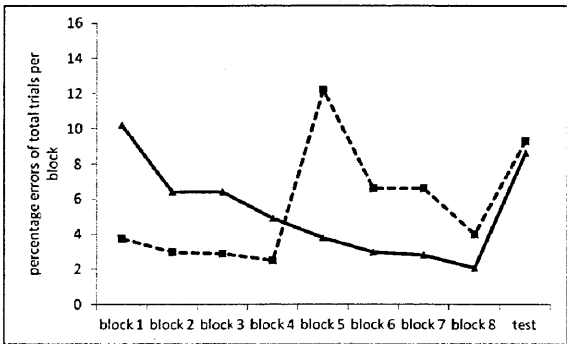
Figure 9.7: change in percentage of errors made as a proportion of total number of trials per block.

a) Multiple-triplet task



Key: ◆ solid line 422-letter-first
■ dashed line end-letters-first

b) Shapes task



Key: ▲ solid line orientation-change-first
X dashed line missing-shape-first

9.3.3.2 Response times

There was no significant correlation between overall error rate in training and overall RT for any of the tasks: multiple-triplet 422-letters-first, $r(21) = .084$, $p = .703$; end-letters-first, $r(21) = .046$, $p = .836$; shapes task, orientation-change-first, $r(19) = -.02$, $p = .932$ and missing-shapes-first, $r(20) = -.065$, $p = .775$. This indicates there was no speed-accuracy trade-off in any of the tasks.

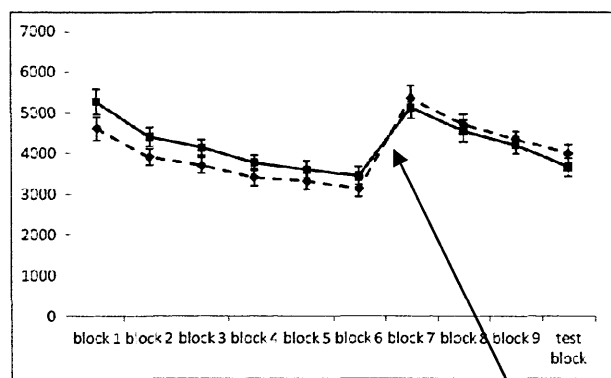
Figure 9.8 shows that response times decreased during each task. For the multiple-triplet task, with end-letters, the RTs for the incorrect stimuli were slightly slower than the correct stimuli, reflecting the fact that each stimulus had to be fully processed for both correct and incorrect, unlike 422-letters, where incorrect stimuli

could be decided after the first triplet. For 422-letters there was some convergence of RTs for correct and incorrect stimuli, indicating greater speeding for the correct stimuli. For the shapes task, the matching stimuli were always slower than the differing stimuli and there was more convergence between matching and differing for the missing-shape part of each task.

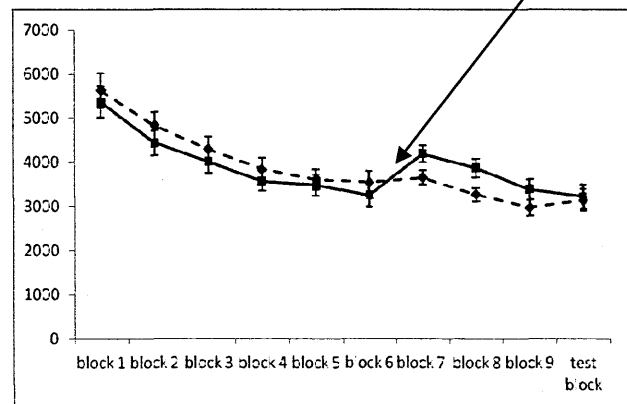
Figure 9.8: change in response times over the course of each task. Error bars represent the standard error of the means

Key: solid line – correct stimuli, broken line – incorrect stimuli

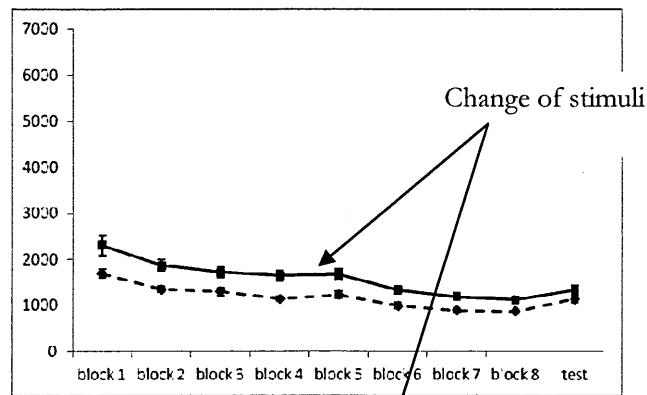
a) Multiple-triplet: 422-first



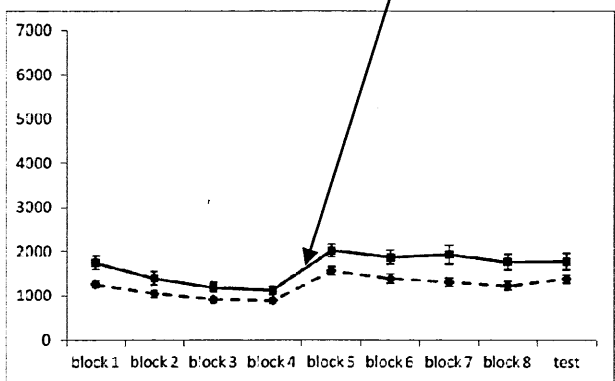
b) Multiple-triplet: end-letters first



c) Shapes: orientation-change-first



d) Shapes: missing-shapes-first



The results of repeated measures ANOVA on the RTs by Block for each stimulus set are given in Table 9.6. RTs reduced across blocks with similar stimuli but tended to increase when the stimuli set changed and in the test block when irregular stimuli were introduced. At both points this increase was not always significant. The only exception was the test block in the 422-letters-first task, which was a significant decrease.

9.3.3.3 “String-length effect”

One of the indicators of Information Reduction is an increased speeding in trials using longer strings or stimuli containing more shapes compared to the shorter ones over the course of the task. This can be ascertained by computing the regression slopes coefficient for ‘string length’ per participant and block and then subjecting these to a one-way repeated measures ANOVA by Block.

Table 9.6: repeated-measures ANOVA on RTs for different stimuli sets and change across sets in the two tasks

Task	Blocks		Change
Multiple-triplet 422-letters-first	Block1-block6	$F(5,110) = 33.07$, $MSE = 24,642,422$, $p < .001$, $\eta_p^2 = .601$	Significant decrease
	Block6-block7 (change of stimuli)	$F(1,22) = 95.03$, $MSE = 43,605,850$, $p < .001$, $\eta_p^2 = .812$	Significant increase
	Block7-block9	$F(2,44) = 21.78$, $MSE = 6,513,239$, $p < .001$, $\eta_p^2 = .497$	Significant decrease
	Block9-test	$F(1,22) = 8.18$, $MSE = 1,990,560$, $p = .009$, $\eta_p^2 = .271$	Significant decrease
Multiple-triplet end-letters-first	Block1-block6	$F(5,110) = 40.44$, $MSE = 43,794,750$, $p < .001$, $\eta_p^2 = .648$	Significant decrease
	Block6-block7 (change of stimuli)	$F(2, 44) = 17.82$, $MSE = 3,416,142$, $p < .001$, $\eta_p^2 = .448$	Significant decrease
	Block7-block9	$F(1, 22) = 13.25$, $MSE = 3,255,361$, $p = .001$, $\eta_p^2 = .376$	Significant increase
	Block9-test	$F < 1$	No change
Shapes orientation- change-first	Block1-block4	$F(3,60) = 25.71$, $MSE = 2,685,976$, $p < .001$, $\eta_p^2 = .562$	Significant decrease
	Block4-block5 (change of stimuli)	$F(1,20) = 1.20$, $MSE = 33,729$, $p = .286$, $\eta_p^2 = .057$	Non-significant increase
	Block5-block8	$F(3,60) = 51.74$, $MSE = 1,265,377$, $p < .001$, $\eta_p^2 = .721$	Significant decrease
	Block8-test	$F(1,20) = 18.65$, $MSE = 585,493$, $p < .001$, $\eta_p^2 = .483$	Significant increase
Shapes missing-shape- first	Block1-block4	$F(3,63) = 45.38$, $MSE = 1,670,534$, $p < .001$, $\eta_p^2 = .684$	Significant decrease
	Block4-block5 (change of stimuli)	$F(1,21) = 118.72$, $MSE = 6,832,496$, $p < .001$, $\eta_p^2 = .85$	Significant increase
	Block5-block8	$F(3,63) = 11.48$, $MSE = 525,853$, $p < .001$, $\eta_p^2 = .343$	Significant decrease
	Block8-test	$F(1,21) = 4.08$, $MSE = 77,144$, $p = .056$, $\eta_p^2 = .163$	Almost significant increase

For correct strings in 422-letters-first, there was a significant decrease in slopes over the first set of stimuli, block 1 – 6, $F(5,110) = 20.81$, $MSE = 827,128$, $p < .001$, $\eta_p^2 = .486$ and a non-significant decrease in slopes over the second set of stimuli, block 6 – 9, $F < 1$. At the change in stimuli there was a significant increase in slopes block 6 – 7, $F(1,22) = 10.39$, $MSE = 388,046$, $p = .004$, $\eta_p^2 = .321$, and there was a non-significant decrease in slopes from the final training block to the test block, block 9 – test, $F < 1$. The effect size for the decrease with the 422-letters was large and of a similar order to Experiment 1, suggesting that much of the variance here could be explained by an increased speeding for the ‘longer’ stimuli, however, the change in stimuli disrupted the effect.

For incorrect strings in 422-letters-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 6, $F(5,110) = 3.72$, $MSE = 73,141$, $p = .009$, $\eta_p^2 = .145$ and a non-significant increase in slopes for the second set of stimuli, block 7 – 9, $F < 1$. At the change in stimuli there was a significant increase in slopes block 6 – 7, $F(1,22) = 52.21$, $MSE = 1,770,603$, $p < .001$, $\eta_p^2 = .704$ and there was a significant decrease in slopes from the final training block to the test block, block 9 – test, $F(1,12) = 9.13$, $MSE = 155,420$, $p = .006$, $\eta_p^2 = .293$.

These results would suggest that Information Reduction was established with the 422-letters but it did not transfer to the end-letters, for most participants, and consequently participants were more able to spot the irregular stimuli in the test block. The changes in regression slopes are presented graphically in figure 9.9.

For correct strings in end-letters-first, there was a significant decrease in slopes over the first set of stimuli, block 1 – 6, $F(5,110) = 12.68$, $MSE = 761,893$, $p < .001$, $\eta_p^2 = .366$ and a non-significant decrease in slopes over the second set of stimuli, block 6 – 9, $F(2,44) = 1.52$, $MSE = 43,295$, $p = .231$, $\eta_p^2 = .064$. At the change in

stimuli there was a significant increase in slopes, block 6 – 7, $F(1,22) = 4.85$, $MSE = 135,714$, $p = .038$, $\eta_p^2 = .181$, and there was a non-significant increase from the final training block to the test block, block 9 – test, $F(1,22) < 1$. The effect sizes for the decrease in slopes over training was large with the first set of stimuli and medium with the second set, suggesting that variance with both sets could be explained by an increased speeding for the longer strings.

For incorrect strings in end-letters-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 6, $F(5,110) = 15.75$, $MSE = 879,417$, $p < .001$, $\eta_p^2 = .417$. There was a non-significant decrease in slopes for the second set of stimuli, block 6 – 9, $F < 1$, but a significant decrease at the change of stimuli, block 6 – 7, $F(1,22) = 17.78$, $MSE = 609,137$, $p < .001$, $\eta_p^2 = .447$ and a significant increase from the final training block to the test block, block 9 – test, $F(1,22) = 11.61$, $MSE = 299,408$, $p = .003$, $\eta_p^2 = .345$.

These results suggest that Information Reduction may have been established, in some participants at least, with the end-letters but not carried over to the second set of stimuli. However, Information Reduction may have become established in the second set of stimuli (422-letters) for some participants. The changes in regression slopes are presented graphically in figure 9.9. The slopes for correct and incorrect strings were very similar when the stimuli were end-letters, because those not using Information Reduction had to process the whole string for both types. With the 422-letters-first the slopes had started to converge by block 6, but when 422-letters were the second set of stimuli there was little convergence, which could suggest that any Information Reduction occurring in the first set of stimuli was not transferred to the second set.

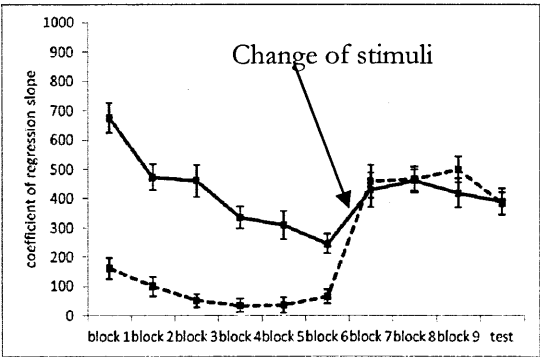
The correlation of the regression coefficient averaged over the final two training blocks and the error rates to irregular stimuli was not significant for 422-

letters-first, $r(21) = .03$, $p = .892$, suggesting that Information Reduction was not established in the second set of stimuli (end-letters). For end-letters-first the correlation was almost significant, $r(21) = -.4$, $p = .059$, suggesting that for some participants Information Reduction was occurring with the second set of stimuli.

Figure 9.9: Multiple-triplet task, the change in coefficient of regression slopes plotted by block (error bars represent the standard error of the means)

Key: solid line - correct strings, broken line - incorrect strings

a) 422-letters-first



b) end-letters-first

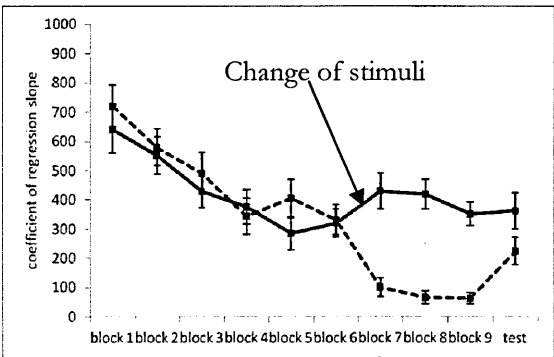
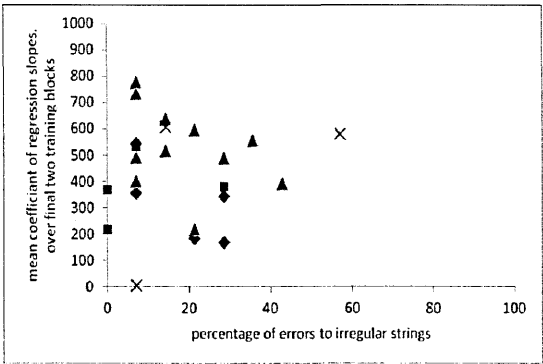


Figure 9.10 shows scatterplots of the two measures, also showing whether the participant indicated on their questionnaire that they had spotted the Information Reduction shortcut and whether they used it or not. It can be seen that there are no reducers in 422-letters-first, not even any who may have only been partially using the strategy, but also half of the participants showed no awareness of the strategy in their questionnaire answers. There were three reducers (13%) in end-letters-first, with low

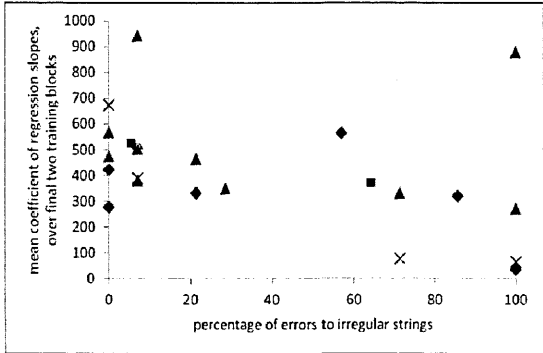
slopes and a high number of errors to irregular stimuli, although one of these may have only partially used the strategy. A further five participants had higher slopes and a high number of errors, so may have been partial reducers. Again, half the participants showed no awareness of any strategy, including three of the partial reducers.

Figure 9.10: Scatterplots showing the regression slopes averaged over the final two training blocks against the percentage of errors to the irregular stimuli, indicating whether they found a shortcut or not.

a) 422-letters-first



b) end-letters-first



Key: ◆ explicitly expressed regularity and indicated use of Information reduction
 ■ aware of regularity but continued checking irrelevant elements
 ▲ did not verbally express regularity
 X no questionnaire returned

It was not possible to distinguish from the questionnaire answers if the strategy had been noticed on the first stimuli set, but was not applied, or only partially applied, on the second set, although this did seem to be the case for some participants. Only one person was able to identify that with end-letters whether the string was correct or

not could be determined simply from the final letter, so it is possible that some thought it was the final triplet.

One additional analysis that was possible with the end-letters task was to check for a decline in the string-length effect for the final triplets. The step-like nature of the stimuli, using gaps of 2-5 between the letters of the final triplet, meant that a longer time should be taken for longer gaps, but if participants noticed that they only needed to check the final letter, then this should disappear. This would be the case for both correct and incorrect strings, and was best analysed by examining only the stimuli with a single triplet. Due to the small number of stimuli at each length the correct and incorrect strings were analysed together. Regression slope coefficients were computed per participant and block and then subjected to a one-way repeated measures ANOVA by Block. For end-letters-first (6 blocks) this showed a significant decrease in this additional 'string-length', $F(5,110) = 4.54$, $MSE = 320,950$, $p = .004$, $\eta_p^2 = .171$. From examining the participants' individual slopes, it would seem that two had realised they could use the final letter and a further three had slopes which declined throughout, but never reaching a level that showed no string-length effect. This suggests that they were making use of one or more letters as a guide, but had not realised that all strings could be categorised as correct or incorrect by the final letter. For the other participants, slopes either remained similar throughout the task or fluctuated. For 422-letters-first there was not a significant decrease in the 'gaplength' slopes, over the 3 blocks of transfer to the end-letters task. However, 6 participants showed a steady decrease and one person appeared to have noticed that it was possible to use the final letter only, although this did not translate into not noticing the irregular stimuli in the test block.

For matching stimuli in orientation-change-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 4, $F(3,60) = 4.81$, $MSE = 59,324$, $p = .011$, $\eta_p^2 = .194$ and a significant decrease in slopes for the second set of stimuli, block 5 – 8, $F(3,60) = 20.08$, $MSE = 119,188$, $p < .001$, $\eta_p^2 = .501$. At the change in stimuli there was a non-significant increase in slopes block 4 – 5, $F(1,20) < 1$, and there was a significant increase in slopes from the final training block to the test block, block 8 – test, $F(1,20) = 6.71$, $MSE = 20,108$, $p = .018$, $\eta_p^2 = .251$. Although the effect sizes for the decrease in slopes over training was large using Cohen's classification (cited in Richardson, 2011), that for the first set of stimuli was small compared to Experiment 1, whereas that over the second set was larger, so that there was a greater effect seen with the missing-shapes.

For differing stimuli in orientation-change-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 4, $F(3,60) = 7.97$, $MSE = 68,704$, $p < .001$, $\eta_p^2 = .285$ and a significant decrease in slopes for the second set of stimuli, block 5 – 8, $F(3,60) = 9.56$, $MSE = 74,212$, $p < .001$, $\eta_p^2 = .323$. At the change in stimuli there was a significant increase in slopes, block 4 – 5, $F(1,20) = 15.18$, $MSE = 109,164$, $p = .001$, $\eta_p^2 = .431$ and there was a significant increase in slopes from the final training block to the test block, block 8 – test, $F(1,20) = 9.87$, $MSE = 72,092$, $p = .005$, $\eta_p^2 = .33$.

These results suggest that Information Reduction was established with the first set of stimuli, orientation-change, and was carried over to the second set, missing-shape, reasonably well, although many of the irregular shapes were spotted in the test block, so processing reverted to taking longer for the stimuli with more shapes. The changes in regression slopes are presented graphically in figure 9.11.

For matching stimuli in missing-shape-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 4, $F(3,63) = 8.90$, $MSE = 123.494$, $p < .001$, $\eta_p^2 = .298$ and a non-significant decrease for the second set of stimuli, block 5 – 8, $F(3,63) = 1.19$, $MSE = 10.962$, $p = .317$, $\eta_p^2 = .054$. At the change in stimuli there was a significant increase in slopes, block 4 – 5, $F(1,21) = 46.49$, $MSE = 614,193$, $p < .001$, $\eta_p^2 = .689$ and there was a non-significant increase in slopes from the final training block to the test block, block 8 – test, $F(1,21) < 1$. The effect size was large for the first set of stimuli, and medium for the second set, indicating that there was some effect occurring here despite it not being statistically significant.

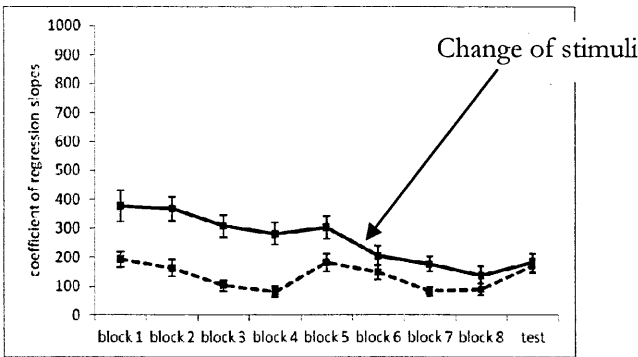
For differing stimuli in missing-shape-first, there was a significant decrease in slopes for the first set of stimuli, block 1 – 4, $F(3,63) = 13.75$, $MSE = 94,032$, $p < .001$, $\eta_p^2 = .396$ and a significant decrease for the second set of stimuli, block 5 – 8, $F(3,63) = 7.92$, $MSE = 49,421$, $p < .001$, $\eta_p^2 = .274$. At the change in stimuli there was a significant increase in slopes, block 4 – 5, $F(1,21) = 5.27$, $MSE = 54,772$, $p = .032$, $\eta_p^2 = .201$ and there was a significant increase from the final training block to the test block, block 8 – test, $F(1,21) = 11.94$, $MSE = 111,132$, $p = .002$, $\eta_p^2 = .362$.

These results suggest that Information Reduction was established in the first set of stimuli, missing-shape. Information Reduction did not seem to be transferred well to the second set of stimuli, unlike the orientation-change-first set, as more of the incorrect stimuli were spotted in the test block. The changes in slopes are presented graphically in figure 9.11.

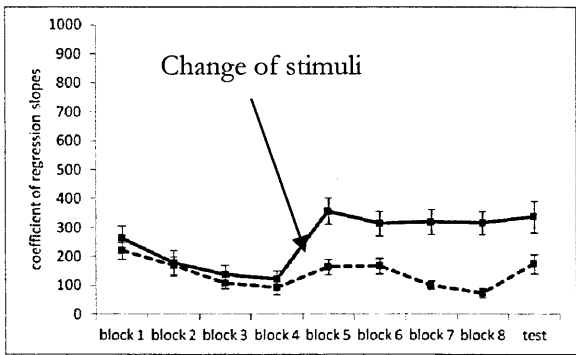
Figure 9.11: Shapes task, the change in coefficient of regression slopes plotted by block (error bars represent the standard error of the means)

Key: solid line – matching stimuli, broken line – differing stimuli

a) orientation-change-first



b) missing-shape-first

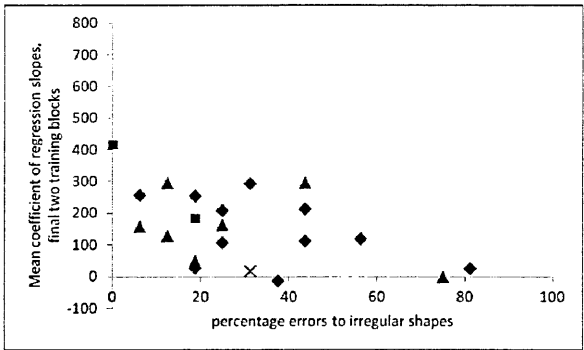


It can be seen that there was more convergence between the slopes for matching and differing stimuli when the stimuli were missing shapes than when they were orientation-change shapes, for both orders of stimuli. Whilst it seems that Information Reduction occurred and was transferred when orientation-change came first and that it occurred for missing-shapes-first, it did not transfer from missing-shapes to orientation-change.

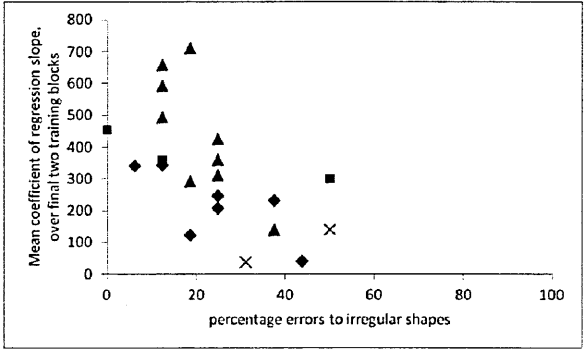
The correlation of the regression coefficient averaged over the final two training blocks and the error rates to irregular stimuli was significant for both orientation-change-first, $r(19) = -.495$, $p = .023$ and missing-shape-first, $r(20) = -.595$, $p = .003$. Figure 9.12 shows scatterplots of the two measures, also indicating whether the participant spotted the Information Reduction shortcut and whether they used it or not.

Figure 9.12: Scatterplots showing the regression slopes averaged over the final two training blocks against the percentage of errors to the irregular stimuli, indicating whether they found a shortcut or not.

a) orientation-change-first task



b) missing-shapes-first task



Key:
 ◆ explicitly expressed regularity and indicated use of Information reduction
 ■ aware of regularity but continued checking irrelevant elements
 ▲ did not verbally express regularity
 X no questionnaire returned

It can be seen that all participants who saw orientation-change-first and who indicated use of Information Reduction on the questionnaire tended to have low slopes and a higher number of errors to irregular stimuli. Two participants (9.5%) could be classified as reducers, although one did not appear to be aware of so doing, and several others seem to have been partially using the strategy. In missing-shapes-first there would seem to be some partial reduction, but slopes were still high for most participants and most of the irregular stimuli were spotted. Also one-third of the participants seemed unaware of the regularity, although one seemed to be using Information Reduction as much as some of those who expressed awareness. This

suggests that the change in stimuli meant that noticing of a possible strategy and use of it was incomplete.

9.3.4 Discussion

In all tasks, it would seem that Information Reduction occurred for the first set of stimuli, since the regression slopes declined significantly, but slopes increased for both correct and incorrect stimuli at the change in stimuli. This suggests that participants reverted to checking the whole of each stimulus and that transfer did not occur. However, it is notable that only in the missing-shapes-first task did slopes for correct stimuli increase after transfer to more than the slopes at the start. In both multiple-triplet tasks the slopes after the change were less than the equivalent slopes for the same stimuli used at the start in the alternate version of the task. Thus it would seem that some learning did transfer in the multiple-triplet tasks, although whether this was anything more than unconscious automatic processes is open to question.

Lack of transfer is also suggested by the fact that slopes for the second set of stimuli did not significantly decrease for most tasks, and by the number of people who showed no awareness of there being any strategy on their self-reports. However, in the orientation-change-first shapes experiment it did seem as if there was some transfer – slopes reduced significantly for the second set of stimuli and two people could be classified as reducers, one being aware of the strategy and one apparently not aware. Since there were no full reducers in the shapes control experiment (Experiment 1), which gave 480 trials, compared to the 320 trials for each stimulus set here, it seems probable that in this task some participants noticed the strategy and transferred it rather than simply discovering and applying it during the second set of stimuli. The data also suggest that some participants transferred

Information Reduction in the end-letters-first task, as there were some identifiable reducers there too. However, again awareness was not high. Some of those with a high error-rate to irregular stimuli still had high slopes, showing that any transfer occurring was not complete.

As with the near-transfer experiment, it is not possible to determine from the questionnaires whether participants were aware, or making use, of the regularity during the first set of stimuli. The additional analysis carried out on the change in slopes for the single triplets in end-letters suggests that some were making use of only the final letter, either for all strings or for some of them, but it is not possible to determine whether this was conscious knowledge or not. A future experiment could examine this in more detail and explore whether conscious awareness is required for transfer to occur. It could be speculated that even if aware during the first set of stimuli, the participant may not have been aware that they transferred Information Reduction to the second set, or perhaps may not have been able to verbalise the new regularity, and thus showed lack of awareness on the self-report.

The percentage of identified reducers in the orientation-change-first task is similar to the reduction seen for the shapes task in the explicit instruction experiment (Experiment 4, Chapter 7). There were also more participants who indicated knowledge of the strategy on their questionnaires and fewer unaware participants than in the other tasks reported here. However, since there appeared to be participants in both orientation-change-first and end-letters-first who were unable to verbalise the strategy on their questionnaires but appeared to be using Information Reduction, it does seem as if conscious awareness is not definitely required for transfer to occur. It is possible that more trials with the first set of stimuli would enable Information Reduction to be more firmly established and this

might increase the amount of transfer seen. However, the experiment is already long and so this would be quite burdensome for participants. An alternative would be to split trials over more than one day, although this can create its own difficulties with participants failing to return.

It is possible, as was seen with the explicit instruction experiment, that some participants were trying to use strategies other than Information Reduction, which had limited success with one set of stimuli, but could not be transferred to the second set. One possible alternative with the multiple-triplet 422-letters-first was the formation of mnemonics for the initial triplet, such as BAG from B(4)G. The final triplet in end-letters did not lend itself to creating mnemonics, and thus would not be a transferable strategy. It was also clear from the RTs that the different stimuli sets were of differing complexity. The results from Doane et al. (1996; 1999) suggest that transfer occurs more easily from the harder task to the easier one – in this case from the end-letters or orientation-change tasks – and when these came first, some Information Reduction was seen in the test block, whereas it was not seen in the opposite direction. Speelman and Kirsner (2001) also found that the disruption to skill improvement in a second task was exacerbated if the task complexity had increased. Developing tasks which were equally complex might indicate whether a change in complexity is a factor in whether transfer is seen or not.

With the end-letters multiple-triplet task, it would appear that most of the reduction in slopes occurred because participants processed only the final triplet, rather than noticing that the final letter was indicative by itself. This would account for the large number of irregular stimuli noticed in the test block and the higher slopes throughout, especially those for the incorrect stimuli. However, if reduction was only to the final triplet, it might be expected that more transfer would be seen,

as it could be considered easier to notice the relevancy had moved from the initial triplet to a final one, or vice versa, to noticing the change from initial triplet to final letter.

A complete lack of transfer could be taken as evidence for Instance theory, since the instances are different between the two sets of stimuli. However, the fact that there may have been some transfer in this experiment, coupled with near transfer seen in the earlier experiment here, in Haider and Frensch (1996) and Haider et al. (2005), suggests that the lack of far transfer has another explanation. Production rules theory would suggest that these results indicate a lack of many overlapping productions between the processes required for each set of stimuli, limiting the amount of transfer that could occur. Since the productions can be unique to each individual (Taatgen, 2013), some participants will have more that are common to both tasks than others, explaining why some participants seem to have been able to transfer but not others. Lack of conscious knowledge of the strategy can be accommodated by the Production rules theory, since this is an explanation of automatic procedural processes, which are generally taken to be unconscious.

Another reason why transfer did not seem to occur could be related to 'set effects'. These occur when people are unable to change their representation of a problem and thus are unable to discover a solution. Spelman and Kirsner (1997) found that strategies developed in training that were not needed in transfer, caused a decrement in performance. This would be the case where the initial strategy e.g. only process the initial triplet as in 422-letters-first, is not required in the end-letters stimuli and, if used, would result in a large increase in errors. Using a variety of stimuli in training would prevent highly specific strategies developing and should encourage more general and therefore more easily transferred strategies. A future

experiment could examine whether training with two intermingled different sets of stimuli would enable transfer of the idea of a strategy to a third set. Another possible experiment would be to include a hint such as that given in Experiment 4, explicit instruction. This could be at the start or between the two sets of stimuli. If the experiment were split over two days then it would even be possible to explore whether a hint had different effects depending on whether Information Reduction had been discovered in the first set of stimuli or not.

Overall, it would seem that most participants did not transfer the strategy, even if they had discovered it in the first set of stimuli, but some did seem to transfer it. It does appear that transfer can occur without conscious awareness, but this needs to be explored further. The transfer seen can be explained by the Production rules theory, but this experiment does not provide any evidence either for or against the Information Reduction hypothesis.

The final chapter will provide an overview of the results from all the experiments and consider the theoretical implications arising from them.

Chapter 10 DISCUSSION

10.1 OVERVIEW

The basis for this thesis was to further investigate the strategy of Information Reduction proposed by Haider and Frensch (1996; 1999a; 1999b) as some aspects of the previously published results needed exploration. Firstly, the fact that the hypothesis was developed solely from the Alphabet Verification task and so the strategy may not be a general learning mechanism, but artefactual to this task. Secondly, the fact that only about half the participants appear to use the strategy and it is not clear why this might be. It could be connected to whether there is conscious awareness of a regularity or not or it could be connected to aspects of the task, training conditions or individual differences between participants. Information Reduction may not be an adaptive process that can be applied in a range of settings. It is thought to operate as a result of implicitly learning during extended practice that some of the incoming information in a stimulus can safely be ignored, and enables performance improvements over and above those that occur from practice alone. Since it has been noted that perceptual ignoring of information appears to occur under many conditions, such as reading labels on food packaging (Gaschler et al., 2010) and shopping online (Gaschler et al., 2015), as well as in occupations such as air traffic control (Lee & Anderson, 2001; Niessen et al., 1999) and radiology (Kundel et al., 2007), it is necessary to elucidate factors that affect adoption of this strategy. In some situations processing less information is more cognitively efficient, thus freeing resources for other tasks, and people may be more productive if they adopted Information Reduction. However, in other situations it may be that use of

Information Reduction could result in unfortunate or even disastrous errors being made.

Haider and Frensch (1996) have referred to Information Reduction as a 'quantitative' change, since less of the stimulus is processed, with irrelevant elements ignored at the perceptual level. This is contrasted with the 'qualitative' change of existing skill acquisition theories, which assume that the whole stimulus is still processed in some way. These theories state that the shift to faster processing occurs subconsciously and gradually, as a result of encounters with individual stimuli (Logan, 1988) or individual processes (Anderson, 1987), with the relevant response, or procedures to obtain that response, retrieved from memory. All accounts are said to result in the aggregated power law noted by Newell and Rosenbloom (1981).

The experimental evidence used to elucidate the mechanism of Information Reduction was obtained solely from the Alphabet Verification task. In this task, which has been described in more detail in Chapter 3, participants are required to verify whether the correct number of letters have been omitted from a sequential alphabetic string. One of the main premises of the Information Reduction hypothesis is that there is a greater speeding for longer alphabetic strings, although Instance theory (Logan, 1988) can also accommodate this finding. The Information Reduction hypothesis suggests that the redundant letters are not processed at all whereas Instance theory states that there is a shift from multi-step algorithmic processing to one-step retrieval of a response. However, Instance theory cannot explain the incorrect categorisations of 'irregular' strings in the test block, since these are effectively new instances and therefore should not be available in memory, if each full stimulus is taken as an instance. Not only this, but it has been found that Information Reduction can be applied to previously unseen stimuli of the same type

(Gaschler & Frensch, 2009; Haider & Frensch, 1996), suggesting a top-down influence. Instance theory cannot account for newly encountered material being processed in the same way as previously encountered stimuli, although Anderson's Production rules theory can, because it posits that the same procedures are used regardless of the content of the stimuli.

Haider and Frensch have demonstrated that many participants who are able to report the regularity show a discontinuity in their RT curve (Haider & Frensch, 2002; Haider et al., 2005). They believe that it is knowledge of the regularity which precedes the discontinuity and that this is shown by increased RT variances in the block preceding the discontinuity. Hence they suggest that Information Reduction is abruptly applied (Haider & Frensch, 2002; Gaschler & Frensch, 2009) so that once the strategy has been noticed, it serves to change behaviour from that point onwards for all stimuli of the same type, even if not previously encountered. Anderson's theory (1987) would also predict this, as it states that all stimuli would be processed in the same way as the production rules develop. However, Instance theory does not necessarily assume that a change in processing is abrupt and applied to all stimuli at the same time, since the processing depends on the number of times each individual stimulus has been encountered.

There is evidence from Haider and Frensch's, and other, experiments that Information Reduction is not used by all participants. Both Logan's and Anderson's theories would predict that everyone would use Information Reduction, since these are data-driven, bottom-up theories stating that automaticity is an inevitable result of practice. Haider and Frensch explain the lack of reduction by some participants by suggesting that all can become aware of the potential short-cut but actually adopting Information Reduction is a conscious decision. Theories about automatic processes

would need modification to allow for the influence of top-down processing seen in the ability to process newly encountered stimuli and the apparent conscious nature of implementation of the strategy.

The fact that only around half the participants become ‘reducers’ during the course of a normal length experiment was identified as an area that warranted further probing. As well as the use of just a single task, Haider and Frensch also provide little consideration of how variable training conditions might affect the adoption of Information Reduction, so these were other areas to be considered. Finally, it was felt that additional work was required on how much consciousness of the regularity in the stimuli was needed for it to be adopted.

The underlying research questions developed were:

- is Information Reduction merely an artefact of the Alphabet Verification task?
- is it possible to identify those using the Information Reduction strategy from the experimental data (error rates and response times) and from self-reports?
- do manipulations of task and/or training conditions affect the number of people adopting an Information Reduction strategy?
- what, if anything, can be learned about the conscious nature of the strategy from manipulations of training conditions and testing participants’ conscious knowledge post-testing?
- are there any individual differences which point to whether someone will be a ‘reducer’ or a ‘non-reducer’?

As a quick resumé of the findings, which will be elaborated further in this chapter, the answers to these questions would appear to be:

- no
- sometimes
- yes
- being conscious of the strategy may aid its usage but does not seem to be either necessary or sufficient
- nothing so far.

The results suggest that there is a large variability in the adoption of Information Reduction both within and between tasks and training conditions. Some participants discover and use it, some discover it but choose not to use, some are apparently not aware but still show signs of usage and some are neither aware nor use it. Some findings, such as those for the multiple-triplet task in Experiment 3 (chapter 6), are quite different to previously reported data (Haider et al., 2005). Individuals do not seem to abruptly adopt and consistently apply Information Reduction, thus this study only provides limited support for Haider and Frensch's account. The results may have implications for the processes theorised to be involved in skill acquisition, particularly those around automatic processes, and implicit learning, including whether and how this could become conscious knowledge. There are also potential practical applications for training in skilled tasks, such as air traffic control and radiography.

10.2 RECAP OF THE EXPERIMENTS CARRIED OUT

10.2.1 Experiment testing new tasks

In this experiment three tasks, analogous to the Alphabet Verification task, were used. The target search task had previously been used (Edmunds, 2005), the

multiple-triplet task was based on a brief description in a conference presentation (Lincourt, Rybash, & Hoyer, 1998) and the shapes task was novel. Information Reduction was demonstrated in all three tasks. The ‘string-length effect’ attenuated over training and more errors were made to ‘irregular’ than to ‘regular’ stimuli in the test block, along with, in some instances, a return of the string-length effect in the test block.

The results suggest that Information Reduction can be seen at an aggregate level in a variety of cognitive laboratory tasks. However, for the shapes and target search tasks all the participants noticed the change in regularity in the test block, whereas only a few did so for the multiple-triplet task. This suggests that in the former tasks Information Reduction had not been fully adopted. Many participants in these two tasks appeared unaware of the regularity, so it could be that Information Reduction is only used consistently once some conscious awareness has developed. A number of participants indicated on their self-reports that they were aware of the regularity and had taken advantage of it, but this was not apparent from their data, which raised the intriguing possibility of ‘partial reduction’. This will be discussed in more detail in section 10.5. It was also clear from the questionnaires that some people were aware of the regularity but did not change their processing.

Overall, the results from all three tasks indicated that people may adopt Information Reduction under some circumstances but not others. This experiment served as a baseline measure for the subsequent manipulations. Due to the limited supply of potential participants, it was necessary to cut down the number of tasks for the other experiments. Variations on the target search task had already been carried out (Edmunds, 2005). It was noted that the string-length effect, as measured in the Block 1 regression slopes, was biggest in the multiple-triplet task and shapes task.

Additionally, these two tasks both showed a greater range of error rate in the test block, therefore it was decided to proceed with these two tasks. All subsequent experiments used both of these tasks.

10.2.2 Feedback manipulation experiment

This experiment was identical to the control experiment, apart from withdrawal of feedback half-way through training, that is, after 240 of the 480 trials. Participants were informed of this and in the multiple-triplet task it had a dramatic effect on usage of Information Reduction. The regression slopes still declined overall, but only two participants (9%, compared to 64% in the control experiment) could be identified as reducers. On the other hand, the results for the shapes task were similar to the control experiment – no participant reduced exclusively but several indicated on their questionnaires awareness of the regularity and that they had made use of it. In both tasks there seemed to be enough Information Reduction occurring to register at the aggregate level, but at an individual level it might be better described as limited or partial. Again there were some participants who seemed unaware of the regularity, but may have been reducing.

10.2.3 Speed pressure experiment

The manipulation that was introduced for this experiment was to emphasise speed over accuracy to the participants, via the instructions given, and it was anticipated that this would increase the adoption of Information Reduction. However, for the multiple-triplet task, there were again fewer reducers than in the control experiment, although more than for the feedback manipulation experiment. Also there was not a clear division between reducers and non-reducers, unlike the first two experiments. This points towards partial usage of the strategy. In the shapes

task, whilst again not having any participants who fully adopted the strategy, there did seem to be more consistent usage than previously. The string-length effect did not reappear in the test block and more participants produced an increased number of errors to inconsistently placed differing shapes, though once again there was still no complete reduction.

10.2.4 Experiment with explicit instruction to use shortcut

The modification from the control experiment introduced here was another variation of the instructions given. Participants were informed that it was possible to find a shortcut to increase processing speed, and encouraged to indicate if they did so, which then took them to the final two blocks where they were asked to apply the shortcut they had noticed. For both tasks there were a number who discovered the strategy (21% in multiple-triplet and 35% in shapes) and in this experiment it was seen that complete reduction was possible in the shapes task. However, the surprising finding was that a third of participants in both tasks thought they had found a shortcut when in fact they had not. The remainder of the participants showed no awareness of any regularity. Despite not indicating knowledge, several in the multiple-triplet task had data intimating that they were fully reducing, which again suggests that conscious knowledge is not required for it to occur.

10.2.5 Transfer experiments

The final two experiments conducted examined how well Information Reduction would transfer to similar tasks after a period of training. The first allowed for near transfer, where the rule to be applied was the same but the stimuli were slightly different. The second needed far transfer to occur – here the rule changed although the stimuli were superficially more similar. Some level of Information

Reduction was seen in both experiments, although this was more certain in the near transfer for all sets of stimuli. It was deduced that some participants were able to successfully transfer the rule in the near transfer experiment and on the whole these were aware of the strategy, suggesting that conscious knowledge may be required for successful transfer to occur. In the far transfer experiment, for most orders of the stimuli, there appeared to be no transfer occurring, although there was potentially some in the orientation-change-first shapes task. Here it did seem as if conscious awareness was not needed, but given the very small number of participants who may have transferred, this conclusion should be treated with caution.

10.3 APPLYING THE RESULTS TO THE RESEARCH QUESTIONS

One of the issues with the Information Reduction hypothesis is that it has essentially been derived from results from one task – the Alphabet Verification task. This could mean that the attributes posited for it are due to the nature of this task or particular characteristics of the stimuli. One way to test this would be to demonstrate Information Reduction in other tasks and under various training conditions. The bulk of this thesis is based on two tasks developed for this purpose, the multiple-triplet task and the shapes task. In order to aid comparisons between studies, these tasks were designed to have the same parameters as the Alphabet Verification task:

- one element that was relevant to fulfilling the task and at least one other element that was irrelevant
- a variable number of irrelevant elements so that the equivalent of the string length effect could be detected
- a method of introducing relevance into the formerly redundant element(s) to test for increased errors/return of the ‘string length effect’

The tasks also addressed one of the criticisms of the Alphabet Verification task in that the stimuli within them had the same perceptual saliency and complexity throughout. This meant that there was no readily available pre-defined cue as to the relevant and irrelevant portions of the stimuli. Additionally, in the shapes task the automatic left-right reading process was avoided.

10.3.1 Information Reduction in other tasks

All the experiments provided evidence that Information Reduction did occur in both the multiple-triplet and shapes tasks, and variations of them. The measures used to determine the presence of Information Reduction were a significantly larger number of errors made to irregular stimuli than regular in the test block and an attenuation of the string-length effect during training. Experiment 4, explicit instruction, contributed support for the appropriateness of these measures. Participants were instructed to use the shortcut they had found in the final two blocks (one training and the unannounced test block). It was noted that those who had indicated knowledge of the regularity had low slopes and a high number of incorrect classifications of irregular stimuli. Overall, then, it was demonstrated that Information Reduction can be seen in a range of laboratory tasks under various conditions. Along with recently reported results for a parity judgement task (Gaschler et al., 2015) and those for the target search task (Edmunds, 2005), it can be concluded that it is not an artefact of the Alphabet Verification task. This provides support for the idea of it being a general learning process, rather than a task-specific phenomenon. It seems to be applied when stimuli contain redundant information with a high degree of regularity.

Whilst the measures used identified a process labelled as Information Reduction in these laboratory tasks, it cannot be stated with certainty that this is the

same process which has been noted in ‘real-world’ tasks such as radiography and air traffic control. Since all the experimental tasks were designed to have the same parameters, to enable comparison between them, it is possible that the Information Reduction seen in these tasks is at least in part an artefact of the task structure.

10.3.2 Determining the number of reducers

The second research question was only partially answered – it was possible, by using the two measures and a correlation between them, to derive a figure for the number of ‘reducers’ in some tasks and under some training conditions but not others. Table 10.1 shows the percentages of reducers found in each experiment.

Table 10.1: percentages of reducers in the various experiments

Experiment		Number of reducers	
		Multiple-triplet task	Shapes task
	Control	64%	Not determinable
	Feedback manipulation	9%	Not determinable
	Speed pressure	23%	Not determinable
	Explicit instruction	21%	7%
	Near transfer	39%/35%	4%/13%
	Far transfer	0%/13%	0%/13%

In the multiple-triplet task most of those identified as reducers from their data could also be identified as such from their self-reports, although in a few cases the participant showed no awareness of the regularity or of having changed their processing. These figures compare to approximately 41% found by Haider and Frensch (1999a) in the relevant-first condition and 55% in the relevant-last condition of the Alphabet Verification task (22 and 23 participants respectively, with 700 training trials). Whilst the number of participants is small in all these experiments,

these variations in numbers point towards reduction being applied differentially from task to task. It is possible that the various tasks may require different amounts of practice for Information Reduction to occur, so direct comparison of the numbers using it must be done cautiously. The multiple-triplet task required participants to carry out several calculations for the longer strings and under basic training conditions it would appear to be more efficient to use Information Reduction for this task than for the Alphabet Verification task, where all strings incorporate a single calculation.

In the shapes task it was generally not possible to determine the number of ‘reducers’ under most training conditions, despite the aggregate data suggesting Information Reduction had occurred and some participants indicating usage in their self-reports. It may be that it would require more practice for Information Reduction to become fully established with this type of task. In all experiments it appeared that a number of people were partially using the strategy, but how many and to what extent could not be quantified. Section 10.5 will consider the types of processing which might come under the heading of partial reduction.

Further analysis of each individual’s data, on a trial-by-trial basis, could potentially reveal more about the processing occurring. This would be similar to the analysis carried out by Haider and Frensch (2002), which examined the mean latencies for the longest strings as a function of practice block. They concluded from this that a discontinuity could be seen for all participants and reflected a change in strategy. A trial-by-trial analysis would be even more fine-grained and could show, for instance, whether a discontinuity occurs at the same time for all ‘string lengths’, which would be predicted from Haider and Frensch’s hypothesis, and whether participants are consistent in maintaining the increased speeding. The analysis could

consider not just the latencies but also whether or not each trial resulted in a correct or incorrect response and may then indicate whether a speed-accuracy trade-off strategy was in operation, even if only for part of the experiment.

10.3.3 Variations in number of reducers

As well as addressing the second research question, the figures in Table 10.1, for both types of task, also answer the third question. Manipulations of task and training conditions do affect the numbers who adopt an Information Reduction strategy. However, changes did not have an equivalent effect across tasks and in some cases seemed to be in the opposite direction to each other. The results from several of the experiments indicated that Information Reduction tended to be abandoned in the multiple-triplet task when training conditions were altered from those used in the control experiment. This occurred under conditions when usage might be considered to be more optimal, such as the requirement to be as fast as possible, or when the participants should be evaluating the stimuli to discover a shortcut, as well as when the participants were unsettled, as in Experiment 2 when feedback was withdrawn. The level of Information Reduction remained stable or even increased in the shapes task. As it was seen under a range of training conditions, this gives support to the hypothesis that Information Reduction is a general learning process, but it may be less robust a phenomenon than has been suggested.

Having additionally explored some individual differences, it seems that the task and training variables are more important for determining adoption of the strategy. The variation in use between tasks and training conditions suggests that there is not a constant proportion of people who are reducers. It would also appear that no-one is an 'always-reducer', using the strategy exclusively whenever they spot a regularity.

Almost all participants in the shapes task noticed some of the ‘irregular’ stimuli in the test block, with only five participants across all experiments having a 100% error rate to these. Some self-reports suggested awareness of the regularity but a decision not to exploit it. The number of ‘reducers’ varying from zero upwards and the existence of ‘deliberate non-reducers’ supports the idea that using Information Reduction is a conscious decision. However, adoption of Information Reduction is not necessarily an all-or-nothing conscious move by participants as has previously been suggested (Haider & Frensch, 2002; Gaschler & Frensch, 2009). Several aspects of the results indicate that it is more complex than hypothesised by Haider and Frensch: some reducers were unable to verbalise the strategy and often partial reduction appears to occur, including times when the participant has reported that they were a ‘deliberate non-reducer’.

10.3.4 Conscious awareness

One of the research questions asks whether anything can be learned about the conscious nature of Information Reduction. It has been hypothesised that implementation occurs in a conscious second stage of the process, following implicit learning of the regularity. The overall results, showing that Information Reduction occurs to different degrees in the tasks and as training conditions vary, could be taken as evidence that it is consciously applied, perhaps when the participant considers that it will reduce processing times. The idea that it is consciously adopted is supported by the confirmation from these experiments that although some participants were aware of the regularity, they chose not to exploit it and indicated such on their self-reports. However, in all the experiments it was apparent that although most of the identifiable reducers were able to verbalise knowledge about it, there were some who were unable to and did not even seem to realise there was any

regularity. The questions started in a general way and then became quite explicit, for example “Did you notice that the errors always followed the first digit in brackets, except for the last set of strings?” Some of those who answered ‘no’ to this question had low slopes and a high error rate to the irregular stimuli, which suggests that they had been reducing. It is possible that some may not have understood this question, but it seems unlikely that all the non-aware users misinterpreted it. It also appeared from the explicit instruction experiment (Chapter 7) that verbalisable knowledge is not needed in order to use Information Reduction. This suggests that it is possible for Information Reduction to occur subconsciously.

The Unexpected-Event hypothesis argues that it is use of the shortcut which leads to conscious awareness, when a faster than expected RT initiates hypothesis testing to find the cause. However, part of the premise of the Unexpected-Event hypothesis is that the unconscious strategy use is intermittent, and is only fully implemented after awareness has dawned. Therefore it could not explain the very high error rate to irregular stimuli seen for some of the non-aware users, which suggests that reduction was more than intermittent. The representational-strength continuum (Cleeremans and Jiménez, 2002) could be compatible with the results, if the strength required for the implicit knowledge to become explicit varies between people and also builds up differentially depending on the task and training conditions.

Whilst it would seem that it is not necessary to be aware of the regularity to use Information Reduction, results from the transfer experiments reported in Chapter 9 point towards explicit knowledge being needed for transfer to occur. This suggests that conscious knowledge facilitates transfer when there is a change to the stimuli or to the rule governing the regularity.

10.3.5 Individual differences

In order to investigate the final research question, a number of personality and cognitive factors were examined via questionnaires following Experiments 4 (explicit instruction) and 5 (transfer). These factors were: distractibility; impulsivity; trust in memory; cognitive miserliness and the 'big five' personality factors of agreeableness, conscientiousness, extraversion, neuroticism and openness to experience. The results suggested that none of the individual difference measures used, with the possible exception of extraversion in the shapes task, would appear to distinguish reducers from non-reducers. They also did not discriminate those who became aware of the potential shortcut from those who did not show awareness within the duration of the experiment. Some of these factors may be relevant in identifying those who notice the regularity at an early stage of practice compared to those who need much more training before it is adopted. Another area where individual differences may be apparent is between the non-aware reducers and the non-aware non-reducers. Alternatively, it may be that factors not tested could account for some of the differences in performance. Some areas that could be investigated are attentional processes and executive functioning. It has been noted that cognitive style, for instance whether someone is a visualiser as opposed to a verbaliser, can affect which strategy is selected from the set possessed by that individual (Roberts & Newton, 2001). Working memory capacity and reasoning ability can also impinge on strategy selection (Schunn & Reder, 2001), so these are other avenues that could be explored. However, it could be that more transitory factors like stress affect awareness and use of Information Reduction.

In summary, the results provide some support for the Information Reduction hypothesis, as well as some evidence against it. Information Reduction does seem to

be a general learning process, but may be neither fully nor consistently applied. However, it must be acknowledged that there may be other processes involved in use of the strategy, including automaticity.

10.4 WHY MIGHT THE NUMBERS OF REDUCERS VARY?

There are a number of possible reasons, which could exist in combination, why the numbers using Information Reduction differed across the tasks. Firstly, the shapes task was processed more quickly than the multiple-triplet task indicating that it was an easier task. Doane et al. (1999) found that the strategy used varied with the difficulty of the task. They concluded that something like Information Reduction had occurred in the difficult version, and these results tally with that. Secondly, the participants were more likely to notice the change in regularity in the test blocks for the shapes task than for the multiple-triplet task, and this could be related to how much of the rest of the stimulus was in the focal area or was perceived. Alternatively it may be related to the ease of the task, or it may be that Information Reduction requires more practice in the shapes task before becoming fully established. Thirdly, it may be that 'full' reduction is more likely to be seen when there is some sort of calculation needed, as in the multiple-triplet task and Alphabet Verification task, rather than when the task is purely visual, as in the shapes task. Fourthly, instance learning may be involved. With both the multiple-triplet task and the Alphabet Verification task the initial triplet occurs a number of times within each block. If the strings are 'chunked', with the initial triplet being one chunk, then this could become an instance, capable of creating many traces (Logan, 1988) or strengthening the representation (Rickard, 1997). This would increase the chance of direct memory retrieval of the response needed. The structure of the shapes task meant that instances were not repeated within blocks, decreasing the number of traces and the

chance of direct response retrieval. Where the required response is directly retrieved then processing of any other parts of the stimulus may be less likely to occur, encouraging the development of Information Reduction.

Rather than the subconscious use of memory, as would happen in an automatic process, there could have been a conscious use, at least in the multiple-triplet task. Some participants did indicate use of memory strategies on their self-reports – for instance using mnemonics like BAG [B(4)G]. Kluger and DeNisi (1996) found that feedback on memory tasks was more effective than for tasks with rules to be followed. The large decrease in number of reducers in the feedback manipulation experiment suggests the multiple-triplet task may be treated by participants as primarily a memory task. Changing the training conditions, and especially removal of feedback, could have affected the willingness to rely on memory, making the participants more conservative and checking the strings thoroughly. Touron and Hertzog (2004a, 2004b) demonstrated that adopting a memory retrieval strategy was affected by confidence in memory ability. Although the results from the individual difference questionnaire suggested that trust in memory did not distinguish reducers from non-reducers, it may be that aware reducers who do not trust their memory become aware non-reducers without feedback. Levels of awareness of the regularity were similar to the control experiment (73% aware in Experiment 1, 64% in Experiment 3) and therefore it would be expected that similar numbers of reducers would be seen. Choosing not to use Information Reduction, if that is what occurred, supports Haider and Frensch's proposal of a voluntarily-controlled strategy but not the idea that it is consistently applied once noticed.

Another reason why the numbers of reducers may vary in the multiple-triplet task is the cognitive (working memory) load associated with calculating several triplets in the longer strings, alongside holding other instructions, such as to be as fast as possible. This could engender a search for a shortcut strategy, which in itself takes up additional working memory resource, as does the evaluation of any potential strategy (Newton & Roberts, 2000). Experiment 4 demonstrated that 31% of participants in the multiple-triplet task thought they had found a shortcut, although they did not choose Information Reduction from the list of options. This suggests that when attempting to find a strategy, the hypothesis-testing can prevent discovery of Information Reduction in some participants. Roberts and Newton (2001) suggest that using or testing ineffective strategies can inhibit the discovery of alternatives. There are several places in the sequence of processes where this inhibition could occur. It could be at the level of implicit learning of the regularity or at implementation of the strategy.

Finally, there is a possibility that there are inherent limitations or problems with the overall methodology employed, or with remote testing of participants, and that this is why the number of reducers varied from experiment to experiment. By structuring the tasks in the same way and employing the same type of analysis as previously used then any methodological weakness is perpetuated. Participants may not have understood the instructions given, although only a few were eliminated from the analyses for recording too many errors and in general all experiments should have been equally affected by such an issue. There may have been experimenter or demand effects, but again it would be expected that all experiments would have been equally affected by these.

The Information Reduction hypothesis advanced by Haider and Frensch would seem to suggest that in the right conditions everyone could become a reducer. One of their experiments suggested that this might be the case, if the amount of practice is increased (Haider & Frensch, 2002). However, this series of experiments has shown that it is remarkably difficult to increase the number of reducers. Given that every manipulation to the multiple-triplet task resulted in fewer reducers compared to the control experiment, it is possible that the number seen in Experiment 1 was the maximum possible for this task. Future research could investigate whether increased practice does increase the number of reducers. Perhaps boredom with the task may be the motive needed for full adoption of Information Reduction.

10.5 PARTIAL REDUCTION

At an aggregate level in the multiple-triplet task the regression slopes for correct and incorrect stimuli converged over the course of training, which is indicative of Information Reduction occurring. There was less convergence in the shapes task. Processing for incorrect stimuli can cease as soon as the error is encountered, so the rest of the stimulus can be ignored, leading to low slopes. If the redundant parts of correct stimuli come to be ignored then the slopes should decline to be equivalent to those for the incorrect stimuli. However, the fact that there was always some difference in the slopes suggests that there was still some processing of the irrelevancies at the end of the training. This could be explained by the fact that some participants were known to not be reducing, but also could reflect 'partial reduction' by other participants. Another factor that suggests that some participants were only partially reducing is that often there was not a clear division between the reducers and the non-reducers in the scatterplots of the final regression slopes

against error rate to the irregular stimuli. The aggregate data suggest that Information Reduction had occurred, even where the number of reducers could not be identified. At various points in this thesis it has been suggested that adopting Information Reduction is not an all-or-nothing process, as has been proposed (Haider & Frensch, 2002; Gaschler & Frensch, 2009), but that many participants only seem to use it some of the time. How 'partial reduction' might be manifested in processing is not known, and this could happen differently in different people, or differently in the same person, even within the same experiment. Variations to training conditions may affect people in diverse ways.

One possibility for partial reduction is that the strategy was applied to most or some stimuli, but a variable number of randomly chosen ones were fully processed. A number of self-reports from all tasks and experiments indicated that the regularity was checked first, followed some of the time by checking the rest of the stimulus. This might be termed residual checking and the level at which this occurs could vary between participants, with some being more vigilant than others. Residual checking was apparent in the incorrect training stimuli. Processing of these should always cease once the error has been found, giving a zero string-length effect. It was noted that this did not always occur and whilst the string-length effect was small, it was still present. Attentional slippage, where occasionally unattended, irrelevant items become attended has been described (Lachter, Forster, & Ruthruff, 2004). This transfer of attention may be inadvertent, but can occur when the irrelevant information is available at the same time as the relevant. Under these conditions attention may be shifted to the irrelevant item after the target has been identified. From a survival point of view, it would be important to discover whether information which had been irrelevant had become relevant and relatively infrequent

checks would enable this. Therefore some level of residual checking would make sense for everyday tasks.

If one of the irregular stimuli in the test block happens to be fully processed, then the change in regularity may be noticed, leading to full checking of subsequent stimuli in that block. This was posited by Haider and Frensch (1999a) and they claimed to have seen this in 80% of their participants' data. In the experiments reported here, noticing the change in regularity may account for some having a low error rate to irregular stimuli but it did not seem to be the case for all. For many participants there was no pattern to the irregular stimuli that they correctly or incorrectly classified, although this might simply mean that the change in regularity did not consciously register and cause a reversion to full processing of all stimuli.

Another suggestion for partial reduction is that random parts of some stimuli were processed (Haider & Frensch, 1999b). However, it is hard to imagine how this could result in a steady decline in the string-length effect. One could speculate that this kind of strategy might be adopted under some conditions, such as speed pressure, and it is possible that the results seen for the multiple-triplet task in that experiment could be accounted for by this type of processing.

A further possibility is that participants randomly switched strategies during the experiment, so that use of Information Reduction was not consistent. One such strategy that could have been employed is a speed-accuracy trade-off, and again this might have been more likely to occur when placed under speed pressure. This would be contrary to Haider and Frensch's idea that Information Reduction is consciously adopted at one point in time and affects behaviour reasonably consistently from then on.

Finally, partial reduction may occur because control over the process has wavered. Information Reduction is proposed to be a consciously controlled process. These processes are generally considered to be effortful (Moors & De Houwer, 2006) and thus it would not be surprising if occasionally participants lost control and found themselves processing the entire stimulus. Some participants may be better at maintaining control and thus show less partial reduction. However, a loss of conscious control could not account for unaware users who showed partial reduction, as many in the shapes task seem to do.

Trial-by-trial analysis may be one way to investigate the processing occurring and could shed some light on what participants were doing and which, if any, of the suggestions outlined is correct.

The current Information Reduction model, which proposes that either the strategy is abruptly and fully adopted for all stimuli at the same time (all) (Haider & Frensch, 2002; Gaschler & Frensch, 2009) or not adopted at all (nothing) would need to be extended to explain 'partial reduction'. Partial reduction may be an adaptive response to ensure that irrelevant information had not become relevant.

10.6 INTEGRATING INFORMATION REDUCTION INTO THE THEORETICAL LANDSCAPE

10.6.1 Existing theories

The starting point for the idea of Information Reduction was the observation that the learning and expert-novice literature contained results which suggested that with practice processing becomes limited to task-relevant information (Haider & Frensch, 1996). Experts may use fewer, more relevant, cues than novices (Shanteau, 1992) or may not fixate on the irrelevant items in a display (Lee & Anderson, 2001;

Shapiro & Raymond, 1989). There is long-standing experimental evidence from the attention literature of visual stimuli being unattended at the perceptual level. For instance, Rock and Gutman (1981) found that when two overlapping figures of different colours were used, but the task required attention to just one, that participants were unable to recognise or report the unattended figure. This is considered to have occurred because of a conscious, top-down influence on what was attended, affecting perception.

Existing theories of automaticity, which are generally used to explain performance gains in practice learning, are unable to account for perceptual changes after practice. The literature review (chapter 2) considered these theories in more detail. Foremost are the Production rules theory (Anderson, 1987) and Instance theory (Logan, 1988). In the former it is the steps required that become encoded, into procedural memory. The number of steps can be reduced by ‘composition’, although the whole stimulus is still processed. In the latter theory it is proposed that each time a stimulus is encountered it creates a trace in memory, including the required response. After a number of identical instances have been encoded it becomes faster to retrieve the response related to that stimulus directly in one step than to perform the steps of the processing algorithm. However, the whole stimulus has to be perceived for the appropriate memory trace to be accessed. A variation on this theory is the Component Power Laws theory (Rickard, 1997), which proposes just one representational ‘instance’ which gets stronger as practice proceeds. All these theories are based on non- or sub-conscious processes.

10.6.2 An alternative mechanism?

Based on the results from a number of experiments using the Alphabet Verification task, one of which confirmed that parts of the stimulus are ignored

(Haider & Frensch, 1999a) an alternative mechanism, Information Reduction, was proposed. This was posited to be a two-stage process (Haider & Frensch, 1996; Haider & Frensch, 1999a; Haider & Frensch, 1999b; Haider et al., 2005). In the first stage a regularity of task-relevant and redundant information in the stimuli is implicitly learned. The second stage involves this implicit knowledge becoming available to conscious awareness resulting in a decision to ignore the irrelevant information and only process the relevant. It is proposed that this second stage is implemented abruptly resulting in a discontinuity in an individual's RT curve over time. However, aggregation of results across a number of individuals, who will have adopted the strategy at different points during training, gives the normal power law curve (Haider & Frensch, 2002; Newell & Rosenbloom, 1981). As well as being proposed as a possible additional or alternative mechanism to automaticity, the Information Reduction hypothesis also touches on theoretical areas around implicit learning and how this could become conscious. These were considered in the literature review (chapter 2). One hypothesis which endeavours to explain conscious awareness of implicitly learned material, which was partially developed using the results from Information Reduction studies, is the Unexpected-Event hypothesis (Frensch et al., 2003). This suggests that the implicit learning affects behaviour and noticing this behaviour triggers explicit hypothesis-testing to determine the cause. Once the causal knowledge is conscious, it is applied consistently to affect subsequent behaviour. Another theory is the representational-strength continuum (Cleeremans and Jiménez, 2002), which suggests that as learning progresses the strength of the representations increases, so that knowledge moves from being held implicitly through explicitly to being automatically applied.

The results from this study confirm the existence of Information Reduction and that it can be learned without instruction, or in other words that it is learned implicitly. Theories of automaticity such as Instance theory (Logan, 1988) or Production rules (Anderson, 1987) assume the learning would be conscious and controlled, only becoming subconscious once automaticity has developed (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Therefore it seems that these theories of automaticity may not explain the type of processing occurring in Information Reduction. Information Reduction can appear in a number of tasks and under various training conditions and this could be taken as evidence for it being a general learning process. However, whilst it may be generally available, the results reported here indicate that it may not be generally used. Other research has found that whilst strategies may be available to all, a number of factors will affect who discovers or uses any particular one. These include individual differences in the way task representations are formed and processed, which could be termed cognitive style, the repertoire of available strategies an individual possesses, as well as their ability to select an appropriate strategy in response to feedback (Newton & Roberts, 2000; Roberts & Newton, 2001; Schunn & Reder, 2001).

In the experiments reported in this thesis there were a number of circumstances, for instance, being required to be as fast as possible, where usage in the multiple-triplet task decreased compared to baseline, rather than increasing. This was contrary to expectations and could indicate that Information Reduction is less robust than Haider and Frensch have suggested. The results obtained here tend to rule out theories of automaticity as sole explanations for the processing occurring. If either instance learning (Logan, 1988) or creation of production rules (Anderson, 1987) leads to Information Reduction, then there should have been the same level of

reduction in Experiments 2 and 3 as seen in Experiment 1, since the stimuli were identical, required the same processing and were seen for the same number of trials. Doane et al. (1999) explain their Information Reduction-like results in terms of a synthesised data-driven model of automaticity incorporating both rule compilation and instance learning (Anderson, Fincham, & Douglass, 1997). Lee and Anderson (2001) suggest that improvements in the speed of execution of different elements of a task are due to different mechanisms, some of which are due to attentional shifts, i.e. reducing fixation time, which occur below the level of awareness. This could be another explanation for the non-aware users.

10.6.3 Is automaticity involved?

The results obtained in this study also point towards conscious awareness being neither necessary nor sufficient for Information Reduction to be adopted, with four types of participant being identified: aware users, non-aware users, aware non-users and non-aware non-users. A mechanism such as that put forward in the Unexpected-Event hypothesis can explain why some participants become aware of the strategy, but aspects of it are at odds with the findings here that Information Reduction may not be applied consistently ('partial reduction', discussed in section 10.5). Additionally, it would not explain why some choose not to use it – if awareness results from noticing that responses are faster than expected, or occurring before the stimulus has been fully processed, then why would someone cease using it once it has passed into consciousness? Another difficulty with postulating that Information Reduction is a fully consciously applied strategy comes from considering the properties of controlled processes. Controlled processing is considered to be effortful, slow, serial and intentional, whereas automaticity is considered to be unconscious, effortless, fast, obligatory and may occur in parallel

with other processes (Moors and De Houwer, 2006). Information Reduction seems to be both fast and effortless and thus may involve some sort of automaticity.

Perhaps it may be consciously applied initially, but after some usage, this develops into an automatic process. This potentially could explain why some reducers seemed unaware post-hoc: they were aware for a period of time during the experiment, but this awareness did not need to be maintained and was lost to some individuals.

If Information Reduction does progress into automaticity then this could be explained by the representational-strength continuum proposed by Cleeremans and Jiménez (2002), possibly in combination with the Component Power Laws theory (Rickard, 1997). This would allow for the implicit learning with the formation of representations which become stronger with practice, so that they progress into explicit knowledge, and finally into an automatic process. The Component Power Laws theory also allows for 'partial reduction', since Rickard's experiments showed that memory retrieval was not implemented for all problems at the same time. For some problems there was an abrupt change and for some it was more gradual, varying even within the same person.

Overall, more reduction was seen when stimuli were repeated, or contained a repeating element such as the initial triplet in the multiple-triplet task. Therefore it would seem that memory for instances can play a part, although in the context of the experiment this could be working memory rather than episodic memory, giving only a temporary advantage. Spacing out practice over two or more sessions could test this further. Reduction did seem to transfer from one stimuli set to another, although it is not certain if the idea of reduction can transfer when the rule changes. More practice with the first stimuli set, so that Information Reduction can be more firmly established before transfer is attempted, might shed further light on whether transfer

can occur when the rule about the regularity changes. Transfer can be explained by the Production rules theory, since productions are not stimulus-specific. Thus it seems that there is a place for some automaticity in the execution of Information Reduction. Proponents of the Information Reduction model reject the notion that theories of automaticity are compatible with the top-down conscious processing they have observed in the Alphabet Verification task (Gaschler & Frensch, 2007). Instead they favour the idea that sometimes strategy change occurs as a result of a continuous, implicit, data-driven and not verbally expressible mechanism and sometimes as a result of abrupt, explicit, top-down and verbally expressible processing. However, there has been no discussion of why there should be two separate mechanisms or how or why one over the other might be chosen for a particular task. A theory which combines elements of the Information Reduction hypothesis with some form of automatic processing may provide a resolution of the various results presented here.

10.6.4 What about attention?

Another theoretical area which could be considered with respect to Information Reduction is that of attention. Attention can be described as the process by which the myriad amount of information impinging on a person's senses every moment is reduced to a manageable level and brought into awareness, enabling successful interaction with the environment. Attention can be both consciously and non-consciously driven. There are parallels between the perceptual changes which appear to occur in Information Reduction and those noted in Broadbent's filter theory for selective attention. It tends to be assumed that this model bases selection purely on physical properties, however the model was adjusted to allow for memory, prior experience and expectations to act on the filter (Broadbent, 1958), thus

accounting for the ‘cocktail party effect’ amongst other experimental results.

Broadbent refers to “*adjusting the internal coding [of the selective filter] to the probabilities of external events*” (1958, p298). Whilst Broadbent was presumably referring to the separation of one incoming sensation from others, the idea could be extended to allow for separating one part of a stimulus from the rest.

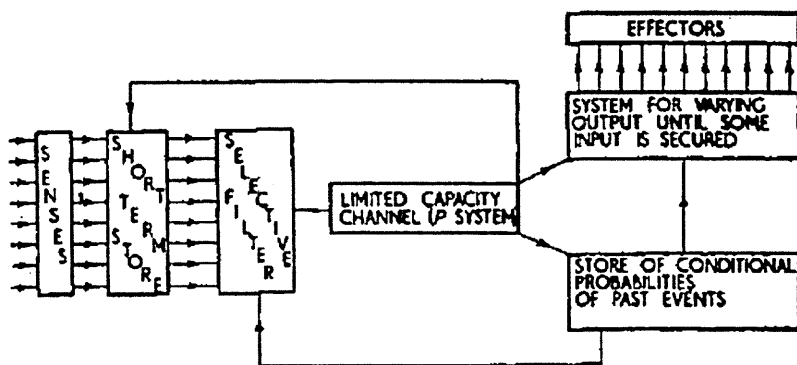


Figure 10.1 Information-flow diagram for selection of stimulus to be processed (Broadbent, 1958)

Additionally, it is known that attention can be affected by top-down processes or ‘biased’. Bias refers to the preferential selection of stimuli in the environment that have some salience for the individual, so that only behaviourally relevant stimuli are processed. Attentional bias is a normal cognitive process driven by the prevailing active goals. It has been shown that at a neuronal level, attention is directed to objects relevant to current behaviour, with suppression of the representations of objects to be ignored (Duncan, Humphreys, & Ward, 1997). Attentional bias has been mainly studied in areas such as emotional disorders and addiction (Field & Cox, 2008; MacLeod, Mathews, & Tata, 1986), where it is quite pronounced. Tasks such as the modified Stroop (Sharma, Albery, & Cook, 2001), the visual-probe task (MacLeod et al., 1986) and the flicker-induced change blindness paradigm (Jones, Bruce, Livingstone, & Reed, 2006) have been used to measure the bias. These tasks, or adaptations of them, could be used following training in Information Reduction experiments to determine if bias is involved. The flicker change detection task has

been used to determine where attention is allocated in processing of food labelling (Gaschler et al., 2010), on the basis that over time people have learned where to attend to find the information that is personally relevant to them. Since participants in Information Reduction experiments are requested to be as fast as possible, and may also find the task boring, a goal to finish quickly should develop and this could cause a bias in where attention is allocated in processing the stimulus.

Lavie and Tsal's ideas on perceptual load (1994) may also have a bearing on some of the results seen here. This suggests that even with a clear physical distinction between relevant and irrelevant information the overall perceptual load determines how much material is selected for processing. This could perhaps explain partial reduction. We might speculate that the shapes task has low perceptual load, thus allowing for more, if inadvertent, processing of the rest of the stimulus and preventing full reduction from taking place. It would also seem that the visual system groups stimuli together, so that this grouping can affect what is attended and what is not (Driver, 2001). This would perhaps account for results suggesting that stimuli with a clear perceptual group, such as the initial triplet in the Alphabet Verification and multiple-triplet tasks, induce more Information Reduction.

Logan has endeavoured to combine Instance theory with the 'executive control theory of visual attention' since he believes that both rely on choice processes and categorisations (Logan, Taylor, & Etherton, 1999; Logan, 2002). Instance theory states that learning, and hence automaticity, is a side effect of attention (Logan et al., 1996). Attention is considered to be essential for encoding of instances, "obligatory encoding", (Logan & Etherton, 1994) and also a stimulus must be attended in order for information associated with the instance to be retrieved, "obligatory retrieval" (Logan, 1988). Attention selects what is perceived and from

this propositions are formed about the stimulus, which determine current performance. These propositions are also encoded into instances for later retrieval (Logan & Etherton, 1994). The combined theory assumes that attention selects the ‘winner’ of the race from the activated instance representations, so that attention is responsible for which object is selected whilst automaticity says how a response to that object was created (Logan et al., 1999). Initially Logan believed that only information relevant to the task was represented explicitly in the instance. However, experiments showed that some attributes, which may guide attention, could also form part of the instance, even if not explicitly required for responding. In other words some attributes were implicitly learned, but only retrieved if needed (Logan et al., 1999). This may create a way to combine Information Reduction with Instance theory.

10.6.5 Working towards developing a theory

Learning seems to progress through the same stages, whether the skill being developed is perceptual-motor or cognitive (Rosenbaum et al., 2001). These stages are considered to be: declarative, when the basics of the task are being learned; associative, when the procedures of the task become more fluent and are compiled into procedures; and finally autonomous, when the procedures become automatic and less susceptible to disruption from external events (Anderson, 1982). Anderson et al. (1997) consider that performance in a skilled task results from a mixture of processes, with a complex set of strategies developing based on both procedural memory (production rules) and declarative memory (instance retrieval). Initially processing is slow, as declarative analogies are drawn from the first examples encountered in order to produce responses, but from these it becomes possible to create procedural production rules. As practice proceeds, examples may be

repeatedly encountered and this gives an opportunity for instances to be stored for direct retrieval. Thus any particular response can be generated by either the automatic use of a production or the automatic retrieval of an instance (if available).

The challenge is to determine how Information Reduction might fit into a theory of skill acquisition. It might be another stage that can occur before, alongside or after the formation of other automatic processes. Alternatively, it may be a completely separate mechanism. The implicit learning of the regularity which seems to occur does not fit with Anderson et al.'s description of early learning being declarative, especially when considering that this never seems to become conscious knowledge for some people. On the other hand, some aspects do seem to suggest that automaticity is involved. However, these experiments demonstrated that Information Reduction is a fragile mechanism, easily affected by changes to training conditions. This intimates that it is not an inevitable result of practice and thus seems to be separate from the automatic processes theorised by Anderson and Logan.

Any theory about Information Reduction needs to consider the implicit nature of the learning and the fact that whilst knowledge about the regularity becomes conscious for some people, it does not for others. How the regularity gets represented may be a key issue here. It may be that an abstracted 'rule' is formed (e.g. "the error always occurs in the initial triplet") or it may be that the representation is more tied to specific instances (e.g. "B(4)G is always correct", aided by this being a memorable 'word'). It has been suggested that in implicit grammar or other rule-based learning tasks either fragments of the grammar are learned (Perruchet, 1994) or during testing items similar to those seen in training are selected (Cock, Berry, & Gaffan, 1994). However, Vokey and Brooks (1994) argue that non-literal abstracted rules about fragments are learned. Huddy and Burton (2002) suggest that the

representation is not static, so that adaptation to various testing demands can occur. The ideas of fragments being memorised and ‘non-static’ representations could be accommodated within Instance Theory, if an instance is not the whole stimulus, since some attributes can be implicitly learned and form part of the instance, only being retrieved if needed (Logan et al., 1999). One possibility is that sufficient fragments are learned as instances and retrieved quickly, to enable faster processing and cause a reduction in the string-length effect. This then triggers conscious hypothesis-testing, as suggested by the Unexpected-Event hypothesis, and some participants discover the rule, enabling them to apply it to all stimuli. This could then become proceduralised into productions.

10.6.6 Individual differences again

For any given task people have a variety of strategies available to them, some previously learned and some which are discovered as the task is practised (Roberts & Newton, 2001). Strategies may be adopted to achieve goals such as increasing accuracy, faster processing or decreasing task load. There is evidence which suggests that strategies are evaluated as to their validity and effectiveness by performance monitoring (Newton & Roberts, 2000; Schunn & Reder, 2001). However, individual differences may prevent correct evaluation and lead to less efficient strategies being used or may mean slower or non-existent adaptation to feedback on errors that indicate a change in strategy is needed (Schunn & Reder, 2001). Individual differences in awareness are also linked to variations between people in their ability for necessary adaptation in their strategy use (Schunn, Lovett, & Reder, 2001). Experiment 4, which gave explicit instruction about the presence of a shortcut, demonstrated that many participants found it difficult to evaluate their processing and discover performance enhancing strategies. Several experiments have shown that

participants are not necessarily aware of using Information Reduction, which would affect their ability to consciously stop using it or change strategy if needed.

It is both theoretically and practically important to identify what individual differences affect the discovery, awareness and use of strategies, and hence performance on tasks. Some professions, such as Air Traffic Controllers, need to be flexible in the use of strategies in a frequent and rapidly changing task environment. Schunn and Reder (2001) suggest that use of inductive reasoning and task expertise predict those who are able to adapt, whilst ability to reason inductively, to learn facts and the limits of working memory indicate how much adaptation can occur. They found that the rate at which adaptation occurred was determined by task expertise and processing speed. They also suggest that more work is needed to determine which factors might be the best predictors across a range of tasks and situations. Testing these individual differences with Information Reduction tasks could shed light on whether they are predictive of it being adopted or not or of the rate at which it is discovered. If they were found to be a factor then one or more of the tasks could become part of an aptitude test for some professions.

10.6.7 Summary of the theoretical implications

The process of Information Reduction impinges on a number of cognitive areas – attention, implicit learning, instance learning, procedural learning and consciousness, as well as metacognitive processes of strategy development, strategy selection and performance monitoring. Information Reduction does not seem to be solely data-driven and bottom-up, although this may account for the first, implicit, stage of the process. Instance memory, particularly if instances can be formed from ‘chunks’ of part of the stimulus, may be relevant in some or all tasks. Productions in procedural memory also seem to play a part and can explain the transfer seen.

Implicit learning allows for regularities in the environment to be abstracted in some way and to affect behaviour. Thus there may be two subconscious elements involved in Information Reduction – automatic processes and implicit learning. Cleeremans and Jiménez (2002) suggest that these two lie at the ends of a strength-of-representation continuum, with conscious processing in the middle. A theory about Information Reduction which involved this kind of continuum would be able to account for the implicitly learned information moving into conscious awareness. However this does not always occur and any theory must also address this. Top-down influences are also apparent in Information Reduction, not least where participants are aware non-users. One way forward may be to consider whether the conscious use of the strategy can develop into automaticity, which would suggest moving further along the continuum proposed by Cleeremans and Jiménez. Further work is needed before a theory which could account for all the results noted can be developed. However the development of theories about the phenomenon will create testable hypotheses, which can then be used in the cycle of enquiry to refine the theory.

Regardless of whether Information Reduction, as seen in these laboratory tasks, has any parallels in ‘real-world’ tasks such as radiography or air traffic control, it has the potential to be a mechanism for investigating across many areas of cognition, particularly the higher-level construct of consciousness. What is perceived depends on where attention is focussed and this may depend on conscious or unconscious processes; automaticity and implicit learning are considered to occur subconsciously but strategy use may depend on conscious or unconscious decisions; transfer between tasks is a debated topic and may also involve conscious awareness. Consequently the tasks developed here could be used to further examine many of these processes.

10.7 FUTURE DIRECTIONS

There are many areas, both theoretical and experimental, in which knowledge and understanding of the phenomenon known as Information Reduction can be advanced. The Information Reduction hypothesis was developed from results using the Alphabet Verification task. It is only recently that alternative tasks, including the multiple-triplet and shapes tasks, have been reported in the literature (Gaschler et al., 2015; Rowell, Green, Kaye, & Naish, 2015). Both the Alphabet Verification task, the target search task and these new tasks, as well as any yet to be developed, could be tested in further experiments to investigate the strategy and its use further. They could also be used to advance understanding of a number of higher level cognitive processes. Experiments could be variations of those already performed or use alternate paradigms, as well as making use of more detailed analysis such as trial-by-trial performance.

Some areas, such as the role of feedback in the adoption of Information Reduction and the effect of changing task instructions, would lend themselves to a variety of manipulations. These may give more insight into partial reduction and possible use of alternate strategies. It may also prove possible to increase the number of reducers over baseline in the multiple-triplet task, which is something not achieved with the experiments conducted so far. Potential ways to test if the number of reducers could be increased would be to increase the number of training blocks or to vary perceptual or cognitive load. Increasing the number of reducers may also increase the level of awareness and give insight into the conscious nature of the strategy.

Additional experiments testing transfer from one task to another could shed more light on whether awareness is required in order for transfer to occur. It would

be useful to equalise the complexity of the tasks and to test for conscious knowledge at points throughout, perhaps using protocol analysis. There is some evidence that if participants are required to verbalise their task goals, transfer to new untrained tasks may be improved (Karbach & Kray, 2009). It would also be interesting to examine if the strategy could be transferred between completely different tasks, such as between the shapes and target search tasks. This could add evidence as to the general nature of the strategy.

Gaschler and Frensch (2007; 2009) showed that Information Reduction develops at the same rate for both frequently and infrequently presented strings. This could be extended to investigate whether Information Reduction would develop if two tasks were intermingled and whether adoption occurs at the same rate for both. Again this could provide evidence about the conscious nature of the strategy and how generalisable it is, although task-switching costs will also need to be taken into account. There may also be individual differences in executive control which mean that some are better at task-switching than others (Logan, 2002).

Previous research has indicated that inconsistent training with around 10% or more of irregular stimuli can prevent Information Reduction developing (Gaschler & Frensch, 2009; Haider et al., 2005). Many experiments, including those reported here, have used consistent training and followed this with a single unannounced test block containing some irregular stimuli. Future experiments could examine how long Information Reduction persists if several blocks with irregular stimuli are presented after training, the percentage of irregular stimuli needed to cause cessation of reduction and whether providing feedback is essential for the change to be noticed. This could link to metacognitive skills of performance evaluation and strategy selection.

Other paradigms which could be employed in Information Reduction studies would be to change or mix modalities, or to require the participants to perform two simultaneous tasks. It is known that automaticity reduces dual-task interference (Logan & Etherton, 1994), so adding in an additional task after Information Reduction has become established may help elucidate if it does involve some automatic processes. As well as more studies using eye-tracking, methodologies like EEG could be utilised. Haider and colleagues (Haider & Frensch, 2002; Haider et al., 2005) suggest that there is a step-change in RTs when Information Reduction is implemented, as a result of conscious awareness of the regularity. One might therefore expect to see changes in ERPs – either their magnitude or location or both – at the point of adoption. This could resolve the issue of whether there is an abrupt change in processing as has been proposed or whether it is less consistent, as the results reported here would seem to suggest.

One other important area to be investigated is why some participants are deliberate non-users. Whilst it can be speculated that this is related to experimenter or demand effects, there is little evidence to support these ideas. Qualitative methods such as post-testing interviews may be more suitable for giving insight into the reasons that someone decides not to use Information Reduction.

10.8 CONCLUSION

The results presented here point towards a variety of usage and awareness of Information Reduction. One of the aims of this study was to investigate whether characteristics of the task, characteristics of the training conditions, characteristics of the participants or a combination of all three were involved in whether or not an individual adopted the Information Reduction strategy. It can be concluded that the first two aspects, characteristics of the task and the training conditions, are definitely

implicated. Future work could relate this to practical situations where Information Reduction is known or thought to occur, to ensure that it is enhanced when needed or suppressed when usage could be dangerous. At the moment there is little evidence for the characteristics of the participants having an effect, but this cannot yet be ruled out entirely.

The results also suggest that some people use Information Reduction (at least occasionally, but frequently enough to show up in the aggregate results) without apparently being aware of doing so. It was clear that some people's non-usage was due to lack of awareness of an available strategy whereas with others it was a conscious decision not to exploit the noticed regularity. More exploration of why people should choose not to use it is needed. There is also evidence that 'partial reduction' may be occurring, although this could encompass a range of processing differences. One that was clear from some participants' self-reports was residual checking and this does seem to be conscious, rather than a consequence of participants occasionally losing control over the reduction process, but this latter possibility cannot be ruled out in all cases. Partial reduction and deliberate non-usage mean that Information Reduction is not the all-or-nothing process hypothesised by Haider and Frensch.

The results are neither well explained by theories of automaticity (e.g. Instance theory) nor by the Information Reduction model alone. They may be better accommodated by a model which brings together both top-down processes and the automatic processes contained within Instance Theory (Logan, 1988) and Production rules (Anderson, 1987), or perhaps by a representational-strength model (Cleeremans and Jiménez, 2002). In order to develop the model it will be necessary to elucidate what process(es) are occurring in 'partial reduction', how much conscious knowledge

individuals have and why or how it is selected from the range of strategies available. It would also be interesting to examine whether 'partial reduction' develops into 'full reduction' with increased practice, especially with the easier tasks. The role of attention within the process also needs further investigation. Further examination of these factors might also advance general knowledge and understanding of higher level cognitive processes. The fact that not all participants use Information Reduction leads to the conclusion that it is not an inevitable consequence of task structure, supporting Haider and Frensch's theory that it is consciously applied. However it may be more sensitive to task and training conditions than previously reported and not as simple or as robust as they have suggested.

Neither the hypotheses proposed by Haider and Frensch about the mechanism of Information Reduction, nor the main existing theories of automaticity, are sufficient to explain the strategy, and a theory of practice learning which incorporates both data-driven automaticity and top-down controlled processes may provide a better overall explanation. Consequently the Information Reduction hypothesis proposed needs to be amended in order to accommodate this study's results.

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APPENDIX 1 – POST-TESTING QUESTIONNAIRES

MULTIPLE-TRIPLET TASK

1. Have you done this type of task before?

If yes, what do you remember about it?

2. Did you notice anything about the letter strings you were asked to verify?
3. Did you notice anything about the errors in the strings?
4. Did you start to do the task differently as you went on?

If so, how?

[new page]

5. Did you notice that the initial letter-digit-letter repeated a number of times, with different numbers of other letters?
6. Did you notice that the errors always followed the first digit in brackets, except for the last set of strings?

If so, did this affect the way you carried out the task and how did it do so?

At what point did you notice this regularity?

7. Did you notice that the error was sometimes in the other letters in the final set of strings?
8. Did you try to remember the letter-digit-letter combinations or use any other memory strategy?
9. Do you have anything else you would like to add about the task?

SHAPES

1. Have you done this type of task before?

If yes, what do you remember about it?

2. Did you notice anything about the shapes you were asked to compare?
3. Did you notice anything about the shape that was different?
4. Did you start to do the task differently as you went on?

If so, how?

[new page]

5. Did you notice that the different shape was always located middle right, except for the last set of shapes?

If so, did this affect the way you carried out the task and how did it do so?

At what point did you notice this regularity?

6. Did you notice that the different shape was sometimes located elsewhere in the final set of shapes?
7. Do you have anything else you would like to add about the task?

TARGET SEARCH TASK

1. Have you done this type of task before?

If yes, what do you remember about it?

2. Did you notice anything about the letter strings you were asked to check?
3. Did you notice anything about the letter you were searching for?
4. Did you start to do the task differently as you went on?

If so, how?

[new page]

5. Did you notice that the first three letters repeated a number of times, with different numbers of other letters?
6. Did you notice that the letter you were searching for was always second from left, except for the last set of strings?

If so, did this affect the way you carried out the task and how did it do so?

At what point did you notice this regularity?

7. Did you notice that the letter was sometimes in a different position in the final set of strings?
8. Do you have anything else you would like to add about the task?

APPENDIX 2 – DICKMAN IMPULSIVITY SCALE

FUNCTIONAL IMPULSIVITY

I don't like to make decisions quickly, even simple decisions, such as choosing what to wear, or what to have for dinner.

I am good at taking advantage of unexpected opportunities, where you have to do something immediately or lose your chance.

Most of the time, I can put my thoughts into words very rapidly.

I am uncomfortable when I have to make up my mind rapidly.

I like to take part in really fast-paced conversations, where you don't have much time to think before you speak.

I don't like to do things quickly, even when I am doing something that is not very difficult.

I would enjoy working at a job that required me to make a lot of split-second decisions.

I like sports and games in which you have to choose your next move very quickly.

I have often missed out on opportunities because I couldn't make up my mind fast enough.

People have admired me because I can think quickly.

I try to avoid activities where you have to act without much time to think first.

DYSFUNCTIONAL IMPULSIVITY

I will often say whatever comes into my head without thinking first.

I enjoy working out problems slowly and carefully.

I frequently make appointments without thinking about whether I will be able to keep them.

I frequently buy things without thinking about whether or not I can really afford them.

I often make up my mind without taking the time to consider the situation from all angles.

Often, I don't spend enough time thinking over a situation before I act.

I often get into trouble because I don't think before I act.

Many times the plans I make don't work out because I haven't gone over them carefully enough in advance.

I rarely get involved in projects without first considering the potential problems.

Before making any important decision, I carefully weigh the pros and cons.

I am good at careful reasoning.

I often say and do things without considering the consequences.

Dickman, 1990

APPENDIX 3 – COGNITIVE FAILURES QUESTIONNAIRE

The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. Please indicate how often these things have happened to you in the last six months.

Do you read something and find you haven't been thinking about it and must read it again?

Do you find you forget why you went from one part of the house to another?

Do you fail to notice signposts on the road?

Do you find you confuse right and left when giving directions?

Do you bump into people?

Do you find you forget whether you've turned off a light or a fire or locked the door?

Do you fail to listen to people's names when you meet them?

Do you say something and realise afterwards that it might be taken as insulting?

Do you fail to hear people speaking to you when you are doing something else?

Do you lose your temper and regret it?

Do you leave important letters unanswered for days?

Do you find you forget which way to turn on a road you know well but rarely use?

Do you fail to see what you want in a supermarket, although it's there?

Do you find yourself suddenly wondering whether you've used a word correctly?

Do you have trouble making up your mind?

Do you find you forget appointments?

Do you forget where you put something like a newspaper or a book?

Do you find you accidentally throw away the thing you want to keep and keep what
you meant to throw away?

Do you daydream when you ought to be listening to something?

Do you find that you forget people's names?

Do you start doing one thing at home and get distracted into doing something else
(unintentionally)?

Do you find you can't quite remember something although it's 'on the tip of your
tongue'?

Do you forget what you came to the shops to buy?

Do you drop things?

Do you find you can't think of anything to say?

Answers to each question are given as one out of:

Never, Rarely, Sometimes, Quite often, Very often

Broadbent et al., 1982

APPENDIX 4 – SQUIRES SUBJECTIVE MEMORY

QUESTIONNAIRE

1. My ability to search through my mind and recall names or memories I know are there is
2. I think my relatives and acquaintances now judge my memory to be
3. My ability to recall things when I really try is
4. My ability to hold in my memory things I have learned is
5. If I were asked about it a month from now, my ability to remember facts about this form I am filling out would be
6. My ability to make a past memory that is 'on the tip of my tongue' available is
7. My ability to recall things that happened a long time ago is
8. My ability to remember the names and faces of people I meet is
9. My ability to remember what I was doing after I have taken my mind off it for a few minutes is
10. My ability to remember things that have happened more than a year ago is
11. My ability now to remember what I read and what I watch on television is
12. My ability to recall things that happened during my childhood is
13. My ability to know when the things I am paying attention to are going to stick in my memory is
14. My ability to make sense out of what people explain to me is
15. My ability to reach back in my memory and recall what happened a few minutes ago is

16. My ability to pay attention to what goes on around me is

17. My general alertness to things happening around me is

18. My ability to follow what people are saying is

Each item is rated on a nine-point scale from Disastrous (-4) through zero to Perfect

(+4)

Squire et al., 1979; van Bergen et al., 2010

APPENDIX 5 – COGNITIVE MISER

Below are 10 problems that vary in difficulty. Try to answer as many as you can.

- 1) A bat and a ball cost £1.10 in total. The bat costs £1.00 more than the ball. How much does the ball cost?

_____ pence

- 2) If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?

_____ minutes

- 3) In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?

_____ days

- 4) Mary's mother had four children. The youngest three are named: Spring, Summer, and Autumn. What is the oldest child's name?

- 5) If John can drink one barrel of water in 6 days, and Mary can drink one barrel of water in 12 days, how long would it take them to drink one barrel of water together?

_____ days

- 6) Jerry received both the 15th highest and the 15th lowest mark in the class. How many students are in the class?

_____ students

- 7) Just after being picked, a 90 lb watermelon was 90% water. But after being left in the sun for a week, only 80% of its weight is water. How much does it weigh then?

_____ pounds

- 8) If you flipped a fair coin 3 times, what is the probability that it would land “Heads” *at least* once?

_____ percent

- 9) A bear loses 20% of its weight during hibernation. If it weighs 100 kg *after* hibernation, how many kg did it weigh *before*?

_____ pounds

10) If you have a pocketful of current U.K. coins, what is the most they could be worth if you cannot make exact change for a pound? (That is, if no combination adds to exactly £1.00).

APPENDIX 6 – INTERNATIONAL PERSONALITY ITEM POOL

On the following pages, there are phrases describing people's behaviours. Please use the rating scale below to describe how accurately each statement describes *you*. Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same sex as you are, and roughly your same age. So that you can describe yourself in an honest manner, your responses will be kept in absolute confidence. Please read each statement carefully, and then fill in the bubble that corresponds to the number on the scale.

NEUROTICISM

Positively keyed

Often feel blue.
Dislike myself.
Am often down in the dumps.
Have frequent mood swings.
Panic easily.

Negatively keyed

Rarely get irritated.
Seldom feel blue.
Feel comfortable with myself.
Am not easily bothered by things.
Am very pleased with myself.

EXTRAVERSION

Positively keyed

Feel comfortable around people.
Make friends easily.
Am skilled in handling social situations.
Am the life of the party.
Know how to captivate people.

Negatively keyed

Have little to say.
Keep in the background.
Would describe my experiences as somewhat dull.
Don't like to draw attention to myself.
Don't talk a lot.

OPENNESS TO EXPERIENCE

Positively keyed

Believe in the importance of art.
Have a vivid imagination.
Tend to vote for liberal political candidates.
Carry the conversation to a higher level.
Enjoy hearing new ideas.

Negatively keyed

Am not interested in abstract ideas.
Do not like art.
Avoid philosophical discussions.
Do not enjoy going to art museums.
Tend to vote for conservative political candidates.

AGREEABLENESS

Positively keyed

Have a good word for everyone.
Believe that others have good intentions.
Respect others.
Accept people as they are.
Make people feel at ease.

Negatively keyed

Have a sharp tongue.
Cut others to pieces.
Suspect hidden motives in others.
Get back at others.
Insult people.

CONSCIENTIOUSNESS

Positively keyed

Am always prepared.
Pay attention to details.
Get chores done right away.
Carry out my plans.
Make plans and stick to them.

Negatively keyed

Waste my time.
Find it difficult to get down to work.
Do just enough work to get by.
Don't see things through.
Shirk my duties.

RESPONSE OPTIONS

Very Inaccurate

Moderately Inaccurate

Neither Inaccurate nor Accurate

Moderately Accurate

Very Accurate

For + keyed items, the response "Very Inaccurate" is assigned a value of 1, "Moderately Inaccurate" a value of 2, "Neither Inaccurate nor Accurate" a 3, "Moderately Accurate" a 4, and "Very Accurate" a value of 5.

For - keyed items, the response "Very Inaccurate" is assigned a value of 5, "Moderately Inaccurate" a value of 4, "Neither Inaccurate nor Accurate" a 3, "Moderately Accurate" a 2, and "Very Accurate" a value of 1.

Once numbers are assigned for all of the items in the scale, just sum all the values to obtain a total scale score.

<http://ipip.ori.org/>

APPENDIX 7 – COMPARISON OF LABORATORY AND ONLINE TESTING

T-tests to compare data collected under laboratory conditions with that collected remotely

Experiment 1: shapes task

Data was collected from 8 participants under laboratory conditions and from 14 participants remotely.

Overall mean RTs for the first training block (lab group mean 1.8s, SD 0.41; remote group mean 1.7s, SD 0.17) were not significantly different from each other, $t(20) = 0.29$, $p = 0.776$ (two-tailed). Similarly mean RTs for the final training block (lab group mean 1.19s, SD 0.17; remote group mean 1.06s, SD 0.25) were not significantly different from each other, $t(20) = -1.31$, $p = 0.204$.

The regression coefficient for the slopes for the first training block (lab group mean 151.7, SD 90; remote group mean 168.1, SD 102) were not significantly different from each other, $t(20) = 0.38$, $p = 0.71$. Similarly the regression coefficient for the slopes for the final training block (lab group mean 96, SD 56.1; remote group mean 59.8, SD 59.4) were not significantly different from each other, $t(20) = -1.4$, $p = 0.176$.

APPENDIX 8 – TESTING FOR AGE EFFECTS

In order to test for any age effects in Experiments 1-3, it was decided to classify participants from their data rather than their self-reports. Those with < 20% errors to irregular stimuli and mean final two training block regression slopes of > 200 were designated as non-reducers, whilst those with > 80% errors to irregular stimuli and mean slopes of < 200 were reducers. All those in-between were ‘indeterminate’.

There were no reducers in the shapes task by these criteria.

Due to the small number of participants, younger participants were taken as those < 35 and older participants were those 45 and above. Table A8.1 gives the contingency tables for the multiple-triplet task and the shapes task. Chi-square tests were carried out. For the multiple-triplet task the number of indeterminate users gave expected cell counts of < 5, so the analysis omitted this category. The results for the multiple-triplet task were: $\chi^2(1, 29) = .32, p = .573, V = .105$, showing no association between age group and reducer type. For the shapes task: $\chi^2(1, 40) = 1.52, p = .218, V = .195$, showing no association between age group and reducer type.

Table A8.1: contingency tables for age group and reducer type, Experiments 1-3

a) multiple-triplet task

	Reducer	Indeterminate	Non-reducer
Younger	8	3	7
Older	6	4	8

b) shapes task

	Indeterminate	Non-reducer
Younger	10	7
Older	9	14

For Experiment 4, participants were classified by whether they indicated finding a shortcut, and if so whether this was Information Reduction. This gave categories of Reducer, Other Strategy and Not Aware (did not indicate any shortcut). Data from both the multiple-triplet and shapes tasks were combined, but even so 4 cells had expected counts of less than 5, due to a small number of participants younger than 35 in this experiment. Consequently no analysis was carried out, as the result would not have been reliable. Table A8.2 is the contingency table for this experiment.

Table A8.2

	Reducer	Other Strategy	Not Aware
Younger	2	1	6
Older	7	6	9

APPENDIX 9 - PARTICIPANT CORRELATIONS

Error rate and RT per block correlated for each participant in Experiment 3.

1. MULTIPLE-TRIPLET TASK

Participant	correlation	p value	Strategy used
1	-0.784	0.021*	Speed-accuracy trade-off
2	-0.558	0.15	Information Reduction (from questionnaire)
3	-0.307	0.46	
4	-0.613	0.106	
5	-0.027	0.949	
6	0.447	0.266	Information Reduction (from questionnaire)
7	0.157	0.711	
8	-0.301	0.468	
9	-0.281	0.5	Information Reduction (from questionnaire)
10	-0.209	0.619	
11	0.461	0.25	Information Reduction (from questionnaire)
12	-0.544	0.163	Information Reduction (from questionnaire)
13	-0.182	0.666	
14	-0.428	0.29	
15	0.262	0.53	
16	0.712	0.047*	
17	0.911	0.002*	Information Reduction (and on questionnaire)
18	-0.122	0.773	
19	-0.354	0.39	
20	0.061	0.886	
21	-0.246	0.557	
22	0.356	0.387	Information Reduction (from questionnaire)

* indicates a significant correlation

2. SHAPES TASK

Participant	r	p value	Strategy used
1	-.417	.411	
2	.224	.670	Information Reduction (from questionnaire)
3	.537	.272	
4	.929	.007*	Information Reduction (and on questionnaire)
5	.768	.075	
6	.439	.384	Information Reduction (from questionnaire)
7	-.3	.564	Information Reduction (from questionnaire)
8	.836	.038*	Information Reduction (and on questionnaire)
9	.008	.987	
10	.774	.071	Information Reduction (from questionnaire)
11	.580	.227	
12	.439	.384	
13	.218	.678	
14	.829	.041*	Information Reduction (and on questionnaire)
15	.795	.059	
16	-.148	.780	
17	.719	.107	
18	.336	.515	
19	.740	.093	Information Reduction (from questionnaire)
20	-.234	.656	Information Reduction (from questionnaire)